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The Nerve Centers

Louisa Burns

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Studies in the Osteopathic Sciences

THE NERVE CENTERS

Volume II

LOUISA BURNS, M.S., D.O., D.Sc.O.
Professor of Physiology
The Pacific College of Osteopathy

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STUDIES IN THE OSTEOPATHIC SCIENCES

Volume I. Basic Principles
Volume II. The Nerve Centers
Volume III. The Physiology of Consciousness
Volume IV. The Blood

By LOUISA BURNS, M.S., D.O., D.Sc.O.

Professor of Physiology
The Pacific College of Osteopathy
Los Angeles, California

PREFACE

This volume is prepared for the use of students of osteopathy, in the class room and in practice. It is hoped that it may add somewhat to the understanding and the skill of those who use it, and thus to their joy in the work and to their usefulness to mankind.

In these discussions it is taken for granted that the reader has already a fairly thorough knowledge of the anatomy and the physiology of the nervous system. Such facts are given here only when they are needed for the sake of clearness. Facts of morphology, however interesting, are mentioned only when they are seen to have some bearing upon etiology, diagnosis or therapeutics. The pragmatic attitude has been desired in deciding the right of certain discussions to a place in these pages.

The descriptions of the experiments are not given in this volume, partly because this matter would add inconveniently to the size of the book, and partly because the description of the tests as given in the first volume of this series may serve for the tests used in preparing the material for this volume.

Nearly all of the drawings were made by Dr. Ada M. Laughlin, of Los Angeles. The photographs were made by Dr. J. Russell Morris, of Los Angeles. I am greatly indebted to their patience and skill. My fellow students of The Pacific College of Osteopathy have been of great assistance to me in

this work. Without their co-operation many of the studies would have been impossible. All needed supplies and apparatus have been freely placed at my disposal, and I am indebted to them all for help and advice.

I wish especially to express my gratitude to the A. T. Still Research Institute, through whose grants of money the work has been facilitated, and whose interest permits the publication of this volume at this time.

LOUISA BURNS.

The Pacific College of Osteopathy,
Los Angeles, California,
March 18, 1911.

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CHAPTER I

THE STRUCTURE OF THE NEURON

The nervous system has been grossly divided into various parts, such as cerebrum, cerebellum, spinal cord, ganglia, and so on. This gross division is convenient for purposes of study, but it must be remembered that it does not represent any logical classification of the parts of the nervous system. Any separation of one of these parts from its fellows can be accomplished only by cutting through numbers of fibers which belong to the cell bodies of other and often distant parts of the nervous system.

The Neuron Theory

The units of which the nervous system is composed are neurons and the tissues which nourish and support them. The unity and independence of the neuron has been demonstrated. This is called the "Neuron Theory," that is, that the neuron is structurally and physiologically an individual, preserving its identity throughout life. It is not capable of independent existence. It has, after a very early period of embryonic life, no power of reproduction; throughout life it requires for its nutrition very complex substances which must be formed by other tissues of the body. It is thus an extremely specialized cell, though it is as independent, as individual, as much a structural and functional unit as is the cell of the liver or of the blood. It seems also true that each neuron, or at least

each group of neurons, is specialized, doing its own work and none other; unable to perform the duties of other neurons, as they are unable to perform its duties. As the death of persons of unusual ability leave work long undone, so the injury or death of these highly specialized cells leave undone those duties for which they were especially adapted.

The external form of neurons varies greatly. (Fig. 1.) The embryonic cells are spherical. By the outgrowths of the axon and dendrites the shape assumes many variations, many of them very complicated.

The processes of the neuron include dendrites and axon. Within the protoplasm lie various deutoplasmic substances. The nucleus, in the adult normal neuron, lies near the center of the cell body. All of these structures, while in the main resembling similar structures of other cells, yet present certain peculiarities.

The Nucleus

The nucleus varies in size both absolutely and relatively to the size of the cell body. Throughout the nervous system two chief classes of cells are to be found, depending upon the size of the nucleus and the cell body. This classification is given by Nissl.

Cells whose nuclei are large, lying within a scanty ring of protoplasm, are called "karyochromes." They resemble embryonic cells, though they may be found during life. The karyochromes have deeply staining nuclei, with the nucleoli rather poorly defined. The protoplasm is very scanty, contains no tigroid masses or pigment, and has no very well defined reticulum. The nucleus may be eccentric. The cell has no well defined axon or dendrites, but may have one or two short prolongations, not to be distinguished as either axon or dendrite. The function of the karyochromes is not known.

"Somatochromes" are of larger size, with nuclei relatively small, lying in the midst of a large mass of protoplasm. Probably the functional part of the nervous system is composed of somatochromes. The somatochromes have nuclei which stain feebly and with difficulty. Their nucleoli stain deeply and are well developed. Both the nuclear and the cytoplasmic reticulum are well defined. The protoplasm surrounds the nucleus about equally on all sides in normal cells. The axons and dendrites are variously developed, becoming of great length in some cases. The cell body and the dendrites contain tigroid masses and pigments in amounts varying with the class of the cell, its place in the nervous system, and its physiological conditions, such as rest, nutrition, age, etc.

The nucleus is permeated by a chromatin network, with knots at the intersections. This network contains within its meshes one nucleolus which stains very deeply and is always — or seems to be always — present. Besides this nucleolus there may be from one to four others, which are sometimes called supernumerary. These stain less deeply and often variably, and they may vary greatly in size as well as in numbers. These supernumerary nucleoli may be simply rather large net-knots.

The centrosome is not found in the neuron after it has reached a stage of development sufficient to render its recognition possible — that is, after it has passed the possibility of reproduction. A few observers have reported centrosomes in the nerve cells of adult brains in the neighborhood of injuries, but these findings have not been substantiated by later studies. It now seems probably true that the later divisions of the neuroblasts were of such a nature as to give the structures concerned in initiating division to the cells which become developed into neuroglia, while the cells which become developed into neurons are thus left without the power of reproduction but with enormously increased possibilities of differentiation along the lines

of irritability and conductivity. Later investigators report the centrosome present in sympathetic cells at a later time.

The function of the nucleus in the neuron is of the same nature as in other cells. It controls the nutrition of the neuron throughout its whole extent. In the case of the cells of the sensory ganglia of the lumbar cord, the peripheral prolongation may be, in a tall man, more than a meter in length, while the centrally directed axon is about equal in length. The nucleus of these cells, placed about midway of the whole length of the neuron, controls the nutrition of the whole.

The Cytoplasm

The cytoplasm of the neuron is of extreme complexity. The spongioplasm is composed of rows of granules which stain with varying degrees of intensity. The fibrils of the spongioplasm extend into the dendrites and beyond the limits of the hyaloplasm, and similar fibrils extend into the axon. The axonic fibrils stain in a manner slightly different, but by some neurologists are considered continuous with the spongioplasm of the cytoplasm. In the meshes of the spongioplasm lie the hyaloplasm and certain deutoplasmic bodies. The hyaloplasm is a homogeneous, viscid substance, which stains very feebly with the protoplasmic dyes. Very little is known of its structure or function.

The Tigroid Substance

The tigroid masses, or Nissl's substance, or chromophilic granules, as they are variously called, lie in the meshes of the spongioplasm of the cell body and the proximal part of the dendrites, but not in the axon or in the axon hillock. (Figs. 1, 2, 3.) These bodies are usually found only when the nerve cells have been fixed very rapidly and stained in a certain manner. Intravitam staining does not demonstrate them clearly, though sometimes they may appear faintly. For this

Fig. 1. Cell from hippocampus of kitten. 100 diameters.

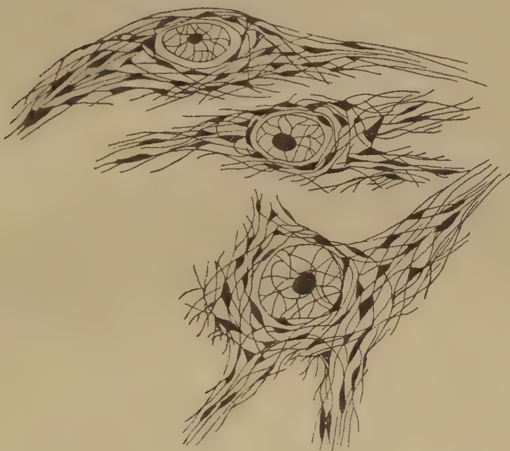


Fig. 2. Cells from dentate nucleus of woman about 30 years old. 800 diameters.

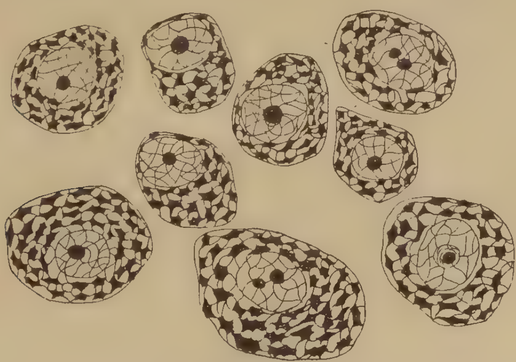


Fig. 3. Sensory ganglion cells. Human embryo of about 5 months. The outlines of the tigroid masses are shown more clearly than on the slide.

reason it is supposed that they do not exist as such during life, but that the appearance is a post-mortem phenomenon. It is, however, a very constant and valuable phenomenon, since the appearance of the tigroid substance changes very profoundly during fatigue, poisoning, or disease. The tigroid substance differs chemically from the other neuron structures. It is not soluble in dilute and concentrated acids, boiling alcohol, cold or boiling ether, or chloroform, and it resists the action of pepsin-hydrochloric-acid longer than do other cell structures. It can be dissolved from the cell, leaving the cytoplasm intact, by the use of concentrated solutions of lithium carbonate. These masses contain iron, phosphorus and the nuclein bases in about the proportions of nuclear material.

The masses are composed of fine granules imbedded in some coagulum-like material. They are usually angular in outline in the normal adult cell. Similar chromophilic masses are to be found in the nerve cells of invertebrates, even those of rather a low type, such as snails, molluscs, etc.

In abnormal neurons, those fatigued, poisoned, or affected by certain conditions of disease, the tigroid substance shows very pronounced changes from the normal. (Figs. 4, 5, 6, 7.) At an early stage of fatigue the masses are found to have rather rounded outlines and to stain less deeply. Later they are found smaller, with even less vigor in staining. With exhaustion, the masses are not to be found, and the cytoplasm of the nerve cells takes a faint blue tint, with perhaps here and there very fine particles with the deeper stain. Under the influence of poisons, excessive heat and certain diseases the variations in the size and staining of the tigroid masses are very characteristic. This matter is discussed at length in Barker's "Nervous System."

Since the tigroid substance shows these constant changes, since it becomes dissipated during cell activity and becomes restored during rest, it is supposed that it represents the

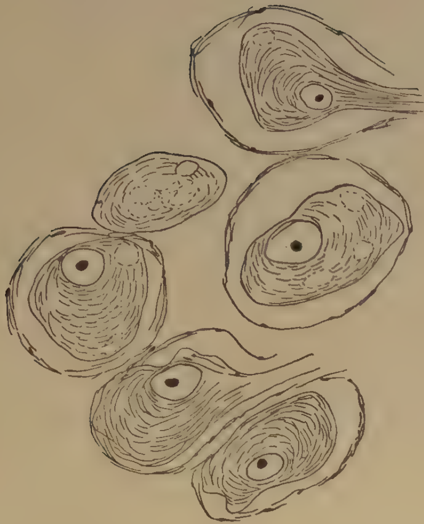


Fig. 4. Sensory ganglion cells of adult dog. The nerves from this ganglion had been stimulated by electricity at intervals of about ten minutes during anesthesia and before death. The vacuolated protoplasm, shrivelled nucleoli, swollen and shrivelled nuclei, large pericellular lymph spaces, disintegrated tigroid masses, show effects of excessive fatigue. 380 diameters.

Fig. 6. Large and small pyramidal cells from somesthetic area of woman with abscess in temporal lobe of same side. Swollen cell bodies, thorn-like dendrites, eccentric nuclei, chromatolysis, swollen and shrivelled nuclei, show effects of abnormal conditions. The small granules are yellow pigment. 175 diameters.

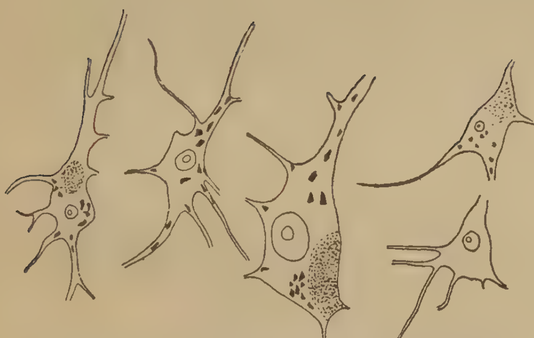


Fig. 5. Cells from cortex of woman with cerebral abscess. Tigroid masses disintegrated, nuclei swollen or shrivelled, cell body swollen, dendrites of irregular contour. 175 diameters.

reserve of cell energy. It is not known whether the disappearance of the tigroid substance is due merely to a mechanical separation of its particles, or whether it is actually used up during cell activity. Since the masses are rebuilt in a remarkably short time, it must be true either that they are simply separated during activity and reunited during rest, or that the materials of which they are composed are very rapidly built up from the lymph surrounding the nerve cell. In certain tests they have been found to be restored to their normal appearance within twenty minutes.

The tigroid masses persist in remarkable manner during certain disease processes. In a section from a brain containing an encysted bullet and an abscess, together with numerous small foci of infection, there are often found cells closely adjacent to the abscess and the inflamed areas, and to the bullet cyst, which contain many fairly normal tigroid masses, while in the same section, not more than the diameter of the cell distant from those with normal tigroid substance, are found others with every appearance of severe degeneration, and with a total absence of the tigroid masses.

The Yellow Pigment

The yellow pigment is another of the deutoplasmic substances of the neuron. This substance occupies certain restricted areas in the cell body. (Figs. 5, 6, 7.) The pigment is composed of rather coarse granules, which are of a light yellow color. It is not dissolved by ether, oil, alcohol, or water; it is not affected by any of the dyes usually used in preparing neurological material. It is stained with osmic acid if it has not been acted upon by ether or alcohol. It is not identical with the pigments of substantia nigra, locus ceruleus, etc.

This pigment is not found in embryonic material. In the human nervous system it is first found in the spinal ganglion

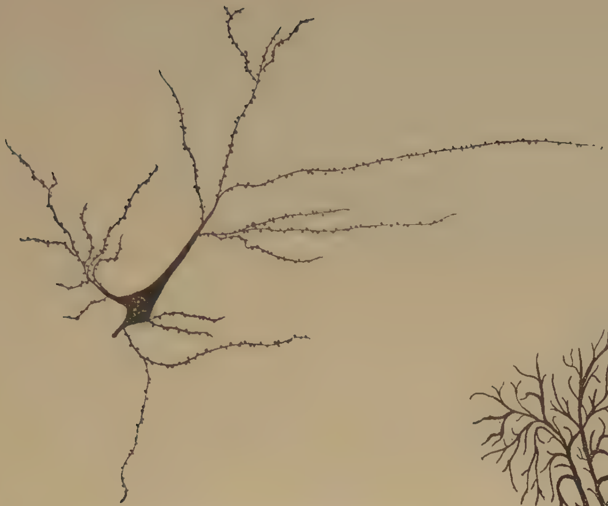


Fig. 11. Pyramidal cell from cortex of half-grown kitten.

Fig. 9. Purkinje cell, kitten, half-grown.

Fig. 7. Cells from somesthetic area of cortex of woman with cerebral abscess. Cell in the center fairly normal. Other cells show chromatolysis. 175 diameters.

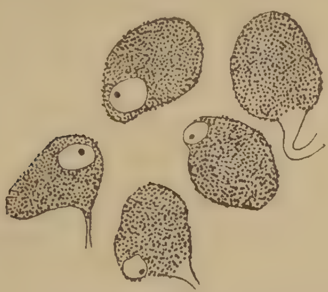


Fig. 8. Cells filled with yellow pigment granules. From nucleus of the reticular formation of woman with abscess in temporal lobe.

Fig. 10. Pyramidal cell from human cortex. 175 diameters.

cells of the child of about six years of age. At nine it is found in the motor cells of the cord. Later it is found in the brain and all through the central nervous system. It is not described as occurring in the cells of the sympathetic system. Under abnormal conditions, as in general paresis, or in premature senility, or in the presence of brain lesions, the amount of the pigment may be enormously increased. It may occupy practically the whole of the cell body, leaving the nucleus half extruded. Sometimes the cell leaves no trace of its existence save that the mass of yellow pigment shows the outline of the cell as it appeared during its life. (Fig. 8.)

The facts known in regard to the yellow pigment present this substance to us as if it were an insoluble waste product of nerve metabolism. If there were some substance, insoluble in the fluids of the body, and formed in very small amounts during a lifetime, such a substance would vary in amount and distribution as the yellow pigment varies.

Other pigments are found in the bodies of the neurons of the substantia nigra, the locus ceruleus, etc., but these seem to be constant during extra-embryonic life.

The Dendrites

The dendrites, as their name indicates, resemble trees. This resemblance is very beautifully shown in the Purkinje cells of the cerebellum. (Fig. 9.) They are protoplasmic prolongations of the cell body, and they have the same staining reactions as the protoplasm of the cell body itself. These branches originate as outgrowths of the cell body. They have broad bases and usually lose in diameter during their length. (Fig. 10.) They branch at acute angles, like the branches of trees, and they exhaust themselves sometimes through frequent branchings. They are usually quite short, and do not leave the vicinity of the cell body. In the case of the sensory neurons of the first order, however, the dendrites attain enor-

Fig. 12. Cell from hippocampus of kitten. The cortex had been stimulated by electricity during anesthesia before death. 100 diameters.

Fig. 17. Anterior horn cell, with pericellular basket. 475 diameters.

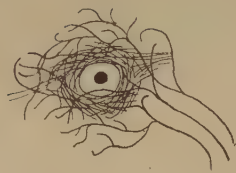


Fig. 18. Basket around Purkinje cell. Human, adult. 470 diameters.

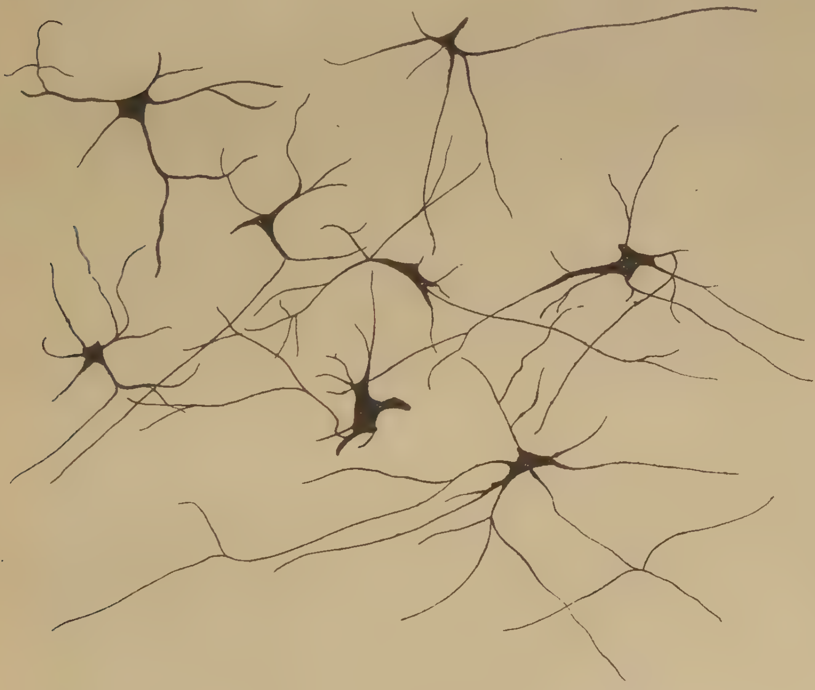


Fig. 13. Multipolar cells from medulla of cat. 40 diameters.

mous length, assume a medullary sheath and neurilemma, and are not to be differentiated, structurally and in adult life, from axons.

The dendrites within the central nervous system are often found studded with small budlike protrusions called "gemmules." (Fig. 11.) It is not certainly known whether these gemmules are an artefact or whether they represent a normal structure of the neuron. In certain diseases of the nervous system, particularly the brain, these gemmules are found greatly swollen and of irregular outline and position. (Fig. 12.) Sometimes they do not appear at all in normal brain material; sometimes they are found plainly in equally normal material. Their nature is thus unknown at present.

Dendrites contain the tigroid substance, as does the body of the nerve cell. Dendrites rarely contain the yellow pigment granules.

The function of dendrites is not certainly known. There is some reason for supposing them to be partly nutritional in function. Nerve cells are unusually large. The surface of the cell body, that is, the possibility of absorbing nutrition and of excreting wastes, is proportionately small in comparison with the mass of the cell, that is, with its need of nutrition and its formation of waste material. This relation seems the more striking and fatal when it is remembered that the metabolism of the neuron is of an extremely rapid and vigorous order, and that its activity is so complex that there is great need for the most speedy renewal of the nutrition and most speedy removal of its wastes. Now by means of the forest of finely-branching dendrites the total surface area of the cell body is greatly increased, and the facilities for the absorption of nutrition and for the removal of wastes is correspondingly increased. There seems very little doubt that this is one important function of the dendrites of the cell. (Figs. 13, 14, 15.)

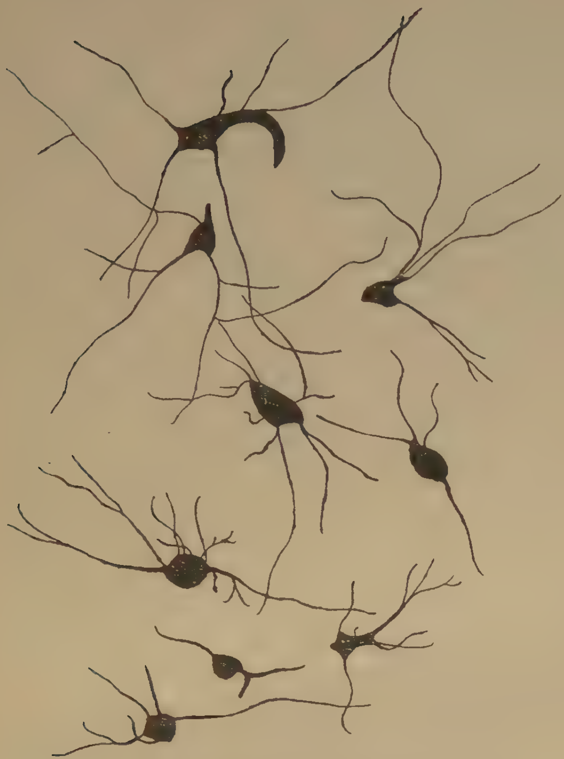


Fig. 14. Cells from corpora bigemina of crow. 175 diameters.

Fig. 15. Polymorphic cells from medulla of adult guinea pig.

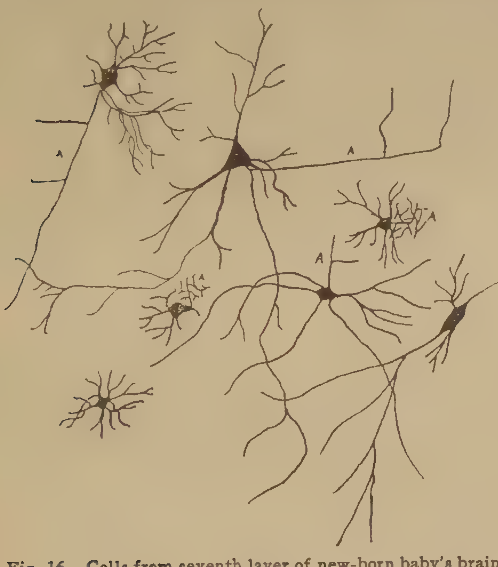


Fig. 16. Cells from seventh layer of new-born baby's brain. A, axon.

Dendrites are known also to carry cellulipetal impulses. Morat insists upon the "polarity" of the neuron — the fact the impulses reach the cell body by means of the dendrites and leave it by means of the axon. This polarity is very well demonstrated in the case of certain neurons.

The branching of the dendrites also affords facilities for very complex relationships with other neurons. A spherical cell body would perhaps be unable to enter into synaptic relations with so many other neurons as one with the wide-spreading system of dendrites which receive the axons and collaterals from many other neurons.

The Axon

An important structure of the neuron is the axon. It is probable that the neurons of the higher vertebrates, at any rate, possess only one true axon, though the sensory neurons of the first order have two processes which are very much alike. Physiologically, however, even these processes differ, since the peripheral prolongation carries cellulipetal impulses; and this process contains the tigroid substance during its early development. In other parts of the nervous system the mon-axonic nature of the neuron is evident.

The axon arises from a part of the cell body which contains no tigroid substance. (Fig. 6.) During embryonic development and throughout life the absence of the tigroid substance in the axon and in the neighboring protoplasm is constant. This space around the origin of the axon is called the "axon hillock" or "implantation cone." It may be placed almost anywhere upon the surface of the cell body, or upon any of the larger dendrites near the cell body. (Fig. 16.)

The axon retains its diameter throughout almost or quite its entire length. It may give off branches called "collaterals," which arise at a right angle to the axon, or may assume a somewhat recurrent direction. Neurons are classified by Golgi

according to the form of the axon. Cells whose axon is long, and passes into the white matter, are called by him "Type I" cells, while those whose axons are short, giving off many very short collaterals which ramify extensively in the immediate neighborhood of the cell body, are called "Type II" cells. It is evident that Type I cells are concerned in relating parts of the nervous system which are more or less distant from one another, while the Type II cells bring into relation those neurons which are placed very near one another.

The spongioplasm of the axon and the axon hillock seems to be continuous with the spongioplasm of the cell body itself. The axon contains fibrils which differ somewhat from those of the cell body and dendrites in staining reactions, though they seem to be more or less continuous with them.

Axons vary in length from the few microns of the Golgi cell of Type II to the meter or more of the axons of the large cells in the anterior horn of the lumbar cord, which terminate in the muscles of the feet, or the axons of the lumbar sensory ganglion cells, which terminate in the nucleus gracilis in the medulla oblongata. The nutrition of the axon, in all its extreme and attenuated length, is dependent upon the integrity of the neuron as a unit. As in every other cell, once any part of the protoplasm is severed from the nucleus, that part soon becomes degenerated and dead. In the case of the long axons the mass of the fiber may be two hundred times the mass of the cell body, and yet the small cell body with its nucleus controls the metabolism of the axon to its farthest extremity.

The axon carries cellulifugal impulses, that is, it carries the nerve impulses from the cell body to other neurons, or to the axon terminations in muscles, glands, etc.

Long axons in the central nervous system are surrounded by the myelin sheath, or medullary sheath, or the white substance of Schwann, as it is variously called. This is a white, homogeneous substance of a fatty nature, and it surrounds

the axon in sufficient quantities to make the area of a cross section of the sheath equal to the area of the cross section of the axon which it encloses. This myelin substance gives the characteristic white glistening appearance of the so-called "white matter" of the brain and spinal cord. The olfactory axons alone of the cerebro-spinal nerves are non-medullated. Axons become medullated in the order of their functional development, though it is not known whether beginning function precedes or follows the medullation of the axons. The axons of the sympathetic neurons have either no medullary sheaths or extremely thin ones, in mammals. In birds the sympathetic axons are usually medullated.

Outside of the central nervous system the axon has another coat, the neurilemma. This is a sheath composed of connective tissue cells, greatly flattened and applied very closely to the medullary sheath. At intervals of about seventy-five times the diameter of the nerve fiber the medullary sheath of the peripheral nerves is interrupted by a circular constriction which permits the neurilemma to lie in contact with the axon itself. These interruptions are called the "nodes of Ranvier." The neurilemmal sheath between one node of Ranvier and the next contains one nucleus, and is thus supposed to be derived from a single connective tissue cell.

The function of the medullary or myelin sheath is not known. It has been supposed to act as a sort of insulator, as a protection to the nerve fiber, as a source of nutrition to the nerve fiber, but there is no sufficient evidence in favor of any of these views.

The neuron is a cell and has the structure characteristic of all cells. It is also a highly differentiated cell, and has, in addition to these, the structures adapted to the performance of these specialized functions. The neuron consists of a cell body together with its prolongations, its axons and dendrites. The cell body varies from four to one hundred and fifty

microns in diameter. The form of the cell varies according to the number, position and size of the dendrites. The existence of a cell wall is problematical. Several authors describe a cell wall of extreme tenuity, others deny its existence. The extension of the spongioplasm into the intercellular gray substance, described in the section on Relations of Neurons, seems to be evidence against the presence of the cell wall.

Nerve Fibers

The peripheral prolongations of the sensory nerves and the axons of the motor nerves are alike called "axis cylinders." The structure of the sensory fiber of the adult is not to be distinguished, histologically, from the motor axon. In the ordinary nerve trunk the two classes of fibers are intermingled with the fine, non-medullated sympathetic axons (fibers of Remak) to make what is called the "mixed nerve."

The nerve trunk is enclosed by the "perineurium" and is divided more or less completely into bundles by the "endoneurium" and the "epineurium," all of which are connective tissue sheaths for the support of the nerve fibers and their vessels. The strength of the nerve fibers depends upon the toughness of these connective tissue sheaths.

The coverings of the nerve fibers, together with the fibers themselves, are nourished as are other tissues, by blood vessels and lymphatics. These are subject to variations in size, according to changes in the systemic blood pressure, and they are innervated by vaso-motor nerves, as are most of the blood vessels of the body. Thus the nerve trunks are subject to hyperemic and ischemic conditions as a result of abnormal vaso-motor impulses, as are other tissues and organs.

In addition to the etiological factors of neuralgia and neuritis which are already fairly well known, the place of such circulatory changes must be recognized.

While the neuritis of a severe form is usually due to alco-

holism, lead, or some other chronic poisoning, the milder types and the neuralgias are often caused by the same structural abnormalities found to be efficient causes of hyperemias and congestions in other tissues, i. e., slight malpositions of vertebrae or ribs, abnormally contracted muscles, reflex irritation from other organs of the body, including the various sources of peripheral irritation, and by the poisons resulting from the retention of the autogenic wastes, or from the use of drugs.

Since the neurilemma is continuous with the sheaths of the sensory ganglia, and since these also are nourished by the blood vessels and lymphatics, themselves innervated by vaso-motor nerves, it is evident that the same abnormal conditions may bring about pain and hyperesthesias due to the ganglionic condition and not associated with motor or vaso-motor disturbance. Such cases are very resistant to ordinary methods of treatment; drugs only purchase temporary relief at the expense of greater pain later. In such cases the correction of the structural abnormalities may permit the normal circulation to be established, and recovery must follow in the degree possible to tissues which have been more or less injured, not only by the original cause of the disturbance, but by the efforts to reduce the pain.

Wallerian Degeneration

The effects of separation from the nucleus are very well shown in the phenomena of Wallerian degeneration, so called after Waller, who gave the first exact description of the condition. When any nerve fiber is cut, the part which is separated from the cell body undergoes a series of changes whose sum is called by this name. The nerve fiber itself begins to show the change within a few hours after section. The fiber becomes granular in appearance, the granules increase in size, and undergo fatty degeneration. The medullary sheath becomes degenerated into droplets, at first very small but

increasing in size. These structures are absorbed, probably in part by the lymphatics and veins, and in part by being used as food by surrounding tissues. The neurilemma cells, which are, of course, not injured except at the very point of section, begin to multiply very rapidly. This multiplication may be due in part to the presence of the increased food supply, but is more probably due to the irritation of the disintegrating nerve fiber and myelin. If regeneration does not occur, these neurilemma cells die and are themselves absorbed. The rapid multiplication of the neurilemma cells produces a solid cord of connective tissue of an embryonic type. The center of this cord, perhaps because of pressure, perhaps because of the lack of nutrition, contains no nuclei. This central portion is called the "band fiber."

Under normal conditions, following section of a nerve trunk, regeneration occurs. The conditions most favorable to regeneration are important.

The ends of the injured nerve should be brought as closely together as possible, and should be sewed together.

The structures to which the nerve is distributed must be kept in as nearly as possible a normal condition. This is best secured, in the case of the muscles, by massage and by electrical stimulation, applied with care. In the case of the skin, for the sake of sensation, the massage is most helpful.

The general health of the patient must be kept as nearly perfect as possible, and his attention should be directed to the paralyzed part of the body. The descending impulses from the cerebrum seem to stimulate the cells in the cord which are in closest relation to the injured fibers by the attentive attitude and the efforts toward movements, and regeneration seems to be somewhat facilitated in this way.

Regeneration occurs most readily and most completely in patients who are young and in good health.

The process of regeneration follows the course which is

to be expected from the physiological conditions. The process of degeneration affects the central end of the stump for a distance of one or several segments. At the upper limit of the area of degeneration the stump of the nerve fiber becomes swollen and bulbous. From this bulbous extremity several fine fibers shoot out, directed peripherically. These fibers are of variable size. One of them soon attains a certain superiority, and the others become atrophied and lost. The remaining fiber grows toward the periphery at a rate approximating a millimeter a day, penetrates the "band fiber" formed by the parenchymous cells of the multiplying neurilemma, and ultimately makes connection with the structures originally innervated by the injured nerve.

In its essential features the process of regeneration of nerve fibers follows the same biological laws which govern the process of regeneration in all living structures. There is nothing beyond the normal conditions which can add to the completeness of the regeneration nor increase the rate of the growth. No drug or stimulant can be used advantageously, nothing can be done which is of the least benefit except to give the growing fibers the rest which they had during their period of most rapid growth, and to keep the muscles and the sensory structures in as nearly as possible their normal condition.

CHAPTER II

THE METABOLISM OF NEURONS

In its physiological activities the neuron greatly resembles the other cells of the body, and, indeed, all other living cells. The essential facts of life are essentially the same everywhere.

As in the case of other cells, the nutrition of the neuron is governed by its nucleus. Any part of the protoplasm, including the prolongations through their greatest extent, which is separated from the nucleus dies, becomes degenerated, and is ultimately digested and absorbed. Under certain conditions, the part of the cell which includes the nucleus may send out a new growth which takes the place of the lost part. Thus the nerve cell, the most complex and highly differentiated cell in the human body, probably, has a power of regeneration which resembles that of the parts of the lower animals. It is the only highly differentiated tissue in the human body which has the power to replace a lost part.

The specific function of the neuron is to receive the effects of certain environmental circumstances, transform these into nerve impulses and ultimately transmit these nerve impulses to the active tissues of the body in such a manner as to initiate those movements, secretions, and positions of the parts of the body which most efficiently preserve the life of the individual and his race. Thus the neuron differs in its metabolism from that of the muscle cell, whose only function is to shorten, or the gland cell, whose only function is to form a specific secretion.

Nutrition

The food of the neuron, like that of the other cells of the body, is provided by the blood, and the lymph which arises from the blood. Each cell is surrounded by its pericellular lymph space, from which it is fed and into which its wastes are poured. The substances required for the best nutrition of the nerve cells are those substances found in the blood flowing through the body of a healthy person. This must include not only the products of the absorption of good foods, well digested, of thorough oxygenation, and thorough elimination of the waste products of metabolism, but it must also include the products of the metabolism of the ductless glands, the so-called internal secretions. The lack of the internal secretions, the lack of any important class of food, or of sufficient oxygen supply, must impair the nutrition of the neuron and cause abnormal functional conditions of the nerve centers. The same disturbances may result from abnormal circulatory conditions. Recovery from such conditions must depend upon the recognition and correction of the fault. It must be recognized that the activity of the nerve centers probably results in the correction of many faults of living and of structural conditions without the intermediation of any particular therapeutic measures. Nothing but the most temporary relief can follow the use either of drugs or of non-drug methods which increase or decrease neuron activity without at the same time correcting the environmental conditions responsible for the disturbance.

The activity of any nerve center, and of the nervous system as a whole, is simply the sum of the activities of the constituent neurons. Any neuron, properly nourished and properly stimulated, performs its proper duties, so long as its structure remains normal. It seems certain, then, that any nerve center must perform its normal duties if its structural

relations are normal, if it is properly nourished, and if it receives the stimuli normal to it. The entire nervous system is but the sum of its parts; if these be normal, its activity must be normal.

Fatigue

The nerve cell has for its specific function the receipt of nerve impulses and their transmission in a more or less modified form to other nerve cells or to the active structures of the body, such as muscles, gland cells, and the like. During the intervals of this activity the nerve cell is supposed to be at rest. During rest the cell body becomes of homogeneous appearance, the vacuoles disappear from protoplasm and nucleus, the nucleus becomes round and centrally placed, the tigroid masses become of large size, of angular outline and capable of staining deeply. During long periods of forced activity the nucleus shrinks and later becomes vacuolated, becomes eccentrically placed, its outline becomes of ragged appearance, and it takes the nuclear stains more deeply than do the rested nuclei. The protoplasm becomes shrunken also, and vacuolated; the tigroid masses become smaller, less angular in outline, and finally disappear; the protoplasm takes a pale, uniform blue tint with the stains used for the demonstration of the tigroid masses.

The functional effects of fatigue upon the neuron are not less marked. The first effect of fatigue upon the neuron is that of a stimulant. Since fatigue is really due to the accumulation of an excess of the waste products of metabolism in the blood, it is probable that it is these more or less acid products which irritate the nervous tissues. This increased irritability usually leads to increased activity, the reflexes are increased, voluntary action is increased, the subject is apt to be conscious of a feeling of well being and of great ability for work. If the real condition is recognized and a short rest is taken, the later more serious symptoms may be avoided. If

the nerve cells are kept in activity, a later stage of decreased irritability is found. The reflexes usually remain increased for a long time, but the more complex neurons in which the higher coördinations are made become unable to act in any normal manner. The condition at this time is that of the neurasthenic. The same sequence of symptoms may be produced by an accumulation of the wastes of metabolism in the blood without any overactivity of the nervous system, by abnormal eliminating organs, by wrong habits of living, eating, breathing, working, etc., or by bony or other structural malpositions which interfere with the circulation of the blood or the activity of the organs of elimination.

Drugs used in the effort to avoid fatigue add to the disturbance, partly by increasing neuron activity beyond normal limits, partly by adding to the poisonous substances in the blood and lymph.

The more complex coördinations, those concerned in the activity of the whole body, the emotional and logical and volitional reactions, are governed by correspondingly complex nerve centers. The individual neurons of these centers are also more complex; each center includes neurons of greater variety of form, and the relations of these to one another are most intricate. These are thus more easily affected by abnormal conditions than are the simpler neurons of the lower and less complex centers. Thus the reflexes and the autonomic activities may remain normal for a long time after the reasoning and memory are less efficient, the loss of these may leave the emotional centers excessively excitable, and so on. It is the higher centers, as a rule almost without exception, which are most seriously injured by excessive fatigue, by the drug addictions, and by the autointoxications.

Occasionally, however, extracellular poisons seem to have a selective effect upon the lower neurons. Thus certain poisons act in a typical manner.

In locomotor ataxia the long sensory fibers are first affected. These carry the impulses concerned in the appreciation of touch and of muscular effort, and the impulses thus carried are concerned in the cerebellar activities of coördination and equilibration. The effect of the poison upon the long, more highly developed fibers is doubtless due in part to the fact that the fibers extend farther from the nucleus than do shorter fibers, and in part to the fact that the cells representing the highest development, the greatest differentiation, are most easily affected by abnormal environmental conditions. The impulses of pain and temperature are carried by the spino-thalmic and the anterior ascending cerebellar tract, and also by short fibers through the spinal gray matter. These thus retain their function and structure in a fairly normal manner under decidedly abnormal conditions.

The relative frequency of lateral sclerosis, affecting the long fibers of the highly developed pyramidal cells, also illustrates the same principle.

Neuron Activity

The resting cell is stimulated to increased activity by changes in the environment. No nerve cells act independently, nor is their activity a matter of chance or whim. There is no change in the functional activity of the neuron except as this is initiated by changes in its environment, or in its structural relations.

For the most part, the change which initiates increased functional activity on the part of a neuron is the impulse sent to it from some other neuron. By far the larger number of all nerve cells in the body are dependent upon other nerve cells for their stimulation. It is by means of the almost infinite variety of numbers of nerve cells which may be affected by comparatively few sensory impulses that we have the inconceivably complex reactions to simple original stimuli.

The sensory neurons of the first order, alone, receive impulses from extra-somatic sources. All of these are affected by changes in the environment of the body, or by changes in the condition of the body. These sensory neurons are stimulated by remarkably small amounts of external variations. The amount of light, for example, which is amply sufficient to arouse perfectly plain images upon the retina is so very small that it is practically impossible for us to imagine that it could be of any physiological influence whatever. Also, the amount of energy displayed in the sound of a bell, the mass of the air thrown into vibration by that slight motion, and the extremely small fraction of the vibrations which reach the listening ear, seems impossibly small. The same conditions apply in the case of smell and taste. It is very evident that the amount of the initial stimulus can bear no mathematical relation to the amount of nerve impulses aroused by it, and still less to the sum of the reflex actions initiated by the effects of the sensory impulses upon the nerve centers. Even more inexplicable is the nature of the effects of these sensory impulses upon the later reactions, as they occur through lives modified by the processes of associative memory.

The nerve cells affected by the impulses from the sensory neurons on the first order transmit these impulses, modified or not modified, to other groups of nerve cells, and these to others, and so on. Ultimately these impulses arouse motor impulses, and thus affect the life history of the individual. Practically all motor impulses are thus initiated, and practically all sensory impulses terminate by initiating motor impulses.

There are certain nerve cells, however, which are stimulated by the changes in their immediate environment, apart from the effects of the impulses from other cells, or apparently apart from these impulses. The nerve cells which are especially recognized in this connection are those of the cardiac

and respiratory centers in the medulla. The nerve cells of these centers are stimulated to increased activity by the presence of an excess of carbon dioxid in the blood, and their activity is decreased by an excess of oxygen in the blood, or, rather, in the lymph which immediately bathes the cells' bodies.

To a certain extent all of the nerve cells of the body are affected by their immediate environment. Not any of the nerve cells act quite in their normal manner in the lack of food or oxygen, or in the presence of an excess of the toxic products of metabolism or of any other poisons, whether produced within the body or used as drug or stimulant.

The Liminal Value

The liminal value, threshold value, and neuron threshold are all terms which are used to express the relative amount of stimulation necessary to affect the activity of the neuron in a perceptible manner. Amounts of stimulation which do not initiate the nerve impulse are called "subminimal." Stimuli which are subminimal may affect the activity of the neuron in some way, since the repetition of subminimal stimuli at frequent intervals may ultimately cause the discharge of a nerve impulse. This condition is called the "summation of stimuli." The periodical discharge of impulses from certain nerve centers is probably due to the summation of the subminimal, or inefficient stimuli. The epileptic fit may be due to summation of abnormal stimuli.

The amount of stimulation necessary to cause the discharge of the nerve impulse by any given neuron is the liminal value of that neuron. The amount of stimulation necessary to cause the discharge of nerve impulses by any nerve center is the liminal value of that nerve center. As the irritability of any cell or any center increases, its liminal value decreases. It is evident that the liminal value of any neuron or any center

may, under abnormal conditions, be either too high or too low, and that the normal activity of the nervous system as a whole or in any of its parts depends upon the existence of the normal liminal value of each of its constituent neurons.

The liminal value of any neuron or any center may be lowered normally by short periods of rest, by frequent stimulation, by the presence of normal nutritive conditions, and the normal elimination of the wastes of metabolism. Normally, the liminal value is raised by long periods of rest, by lack of stimulation.

Under certain abnormal conditions the liminal value may become too high or too low.

Certain poisons, as strychnine, quinine, alcohol, caffeine, etc., and the products of the body metabolism in general, present in the blood in small amounts, lower the liminal value of the neurons. Slightly increased temperature, slightly increased blood pressure, and slight degrees of fatigue, all lower the liminal value of the neurons. Thus the excitement and the increased reflexes and the stimulating effects of these conditions.

Larger amounts of the poisons mentioned and others which will occur to every one, greater increase of temperature, greater increase of blood pressure, all raise the liminal value of the neurons to an abnormal extent. Thus is produced the paralysis of the nerve centers, the inertia of mental activities, and the loss of reflexes associated with the more pronounced degrees of poisoning, or of fevers, or of very high blood pressure.

It is thus seen that the very things which increase neuron activity when used in small amounts, cause the decrease of cell energy and ultimately the destruction of the cells when used in greater amounts. It must be recognized that these methods of increasing or decreasing the liminal value are abnormal — nothing can be added to the normal environment of the neuron

which increases its energy output without at the same time lessening its real value as an efficient part of the nervous system. Any stimulant beyond the normal blood, and the normal stimulation from normally-aroused sensory impulses, must injure the neurons affected, and ultimately lessen the efficiency of the nervous system as a whole.

The Nature of the Nerve Impulse

The term "impulse," which has been applied to the excitation which passes from the cell body over the axon of a neuron, or which passes toward the cell body from a sensory nerve ending, owes its chief merit as a name to the fact that it expresses nothing of the nature of this excitation. In other words, while in most terminology the naming of anything should be done by applying some term which indicates the nature of the thing named; in this case the merit of the name given lies in the fact that it makes no attempt to even suggest the character of the thing named. And this is good, because the real nature of that which passes over the nerve fiber, which causes in muscles contraction, in glands secretion, in cortical nerve cells the changes which affect consciousness, in other nerve cells other action, leading to yet further stimulation — the nature of this thing which produces these variable changes in the cells affected by it, yet remains an inexplicable mystery. So, since there is as yet no adequate conception of the nature of the thing named, the term "impulse," which means only "something impelled" or "sent," is most fortunately applied.

While it is true that we know nothing of the real nature of the nerve impulse, we have determined some facts which seem to govern its action. A consideration of these data may be given some attention, though it must be clearly understood that these studies are very imperfect, and that the investigations in progress may at any time cause our views to be altogether changed. Very much careful study needs to be done

in this field before we may decide any one of many questions now in dispute.

Direction of the Nerve Impulse

The facts which are known to be true in regard to the passage of the nerve impulse over a nerve fiber are many, yet the significance of these facts, and their application to the functions of the nerve fibers and the impulses transmitted are so various, and in some cases so contradictory, that one must necessarily doubt whether any real harmony can exist between so many discordant factors.

The nerve impulse passes over any given nerve fiber always in the same direction. Under experimental conditions, such as the direct stimulation of the nerve trunk, the impulse may be caused to pass in both directions, but this probably never occurs in the unmutilated body.

Electrical Phenomena

The electrical phenomena associated with the passage of a nerve impulse over a nerve fiber are of interest in this connection. When a nerve impulse traverses a nerve trunk, there is produced in the fiber a change in its electrical condition — a wave of negativity which passes at the same rate and in the same direction as the wave of nerve impulse. This can be demonstrated absolutely for motor and sensory nerves, and also for the non-medullated nerves. So constant is this wave of negativity, and so correctly related to the passage of the nerve impulse, that its occurrence has been made a criterion for the nerve impulse itself, in those cases in which the nerve impulse itself is not easily or not possibly determined.

For example, if a nerve trunk be cut, or be removed from the body, and be stimulated midway in its course, there is produced a wave of negativity which travels both peripherally

toward the muscle, which is caused to contract by the associated nerve impulse, and there is also produced a wave of negativity which travels centrally — that is, in the direction opposite to that traversed by the impulses normally carried by the nerve experimented upon. The occurrence of this wave of negativity is held as evidence that under this condition the nerve impulse can be carried in both directions.

The occurrence of similar waves of negativity in sensory nerves has aided in the investigation of certain physiological problems associated with these nerves also.

The manner in which the passage of nerve impulses over the fibers is affected by electrical reactions is also of interest. If the electrodes carrying the continuous current are placed upon any nerve, there is thus produced, at the time of the making of connection, and again at the time of breaking the connection, the muscular contraction which should ensue upon the normal stimulation of that nerve. During the continuous passage of the unvarying current from the non-polarizable electrodes through the nerve, there is not produced any muscular contraction. But during this time there is produced in the nerve trunk certain modifications of its activity. If the current be an ascending one — that is, if the negative electrode be placed nearest the muscle — then there is produced in the nerve trunk below the negative electrode a condition called catelectrotonus, in which the excitability of the nerve is increased. At the same time, above the positive electrode, there is produced a condition called anelectrotonus, in which the excitability of the nerve is decreased. The part of the nerve trunk which lies between the two electrodes is called the interpolar section; the area nearest the anode is in a condition of anelectrotonus, the part nearest the cathode is in a condition of catelectrotonus. If the current be a weak one the catelectrotonic area is larger; if the current be strong, the anelectrotonic area may occupy nearly the whole of the interpolar

space. Indeed, a very strong current may cause an anelectrotonic condition of the whole nerve subject to the experiment.

By several investigators the phenomena associated with electrotonus have been produced by various models of wires in paraffine, with weak currents of electricity passing in various directions through them. These imitations indicate that the nerve impulse follows many of the laws governing the electrical current, and also that electricity is associated with nervous activity. If these conditions were recognized, and no others, the conclusion would be fairly just that in dealing with the nerve impulse we are dealing with some more complex manifestation of electricity. But this is not the case — there are other no less important phenomena to be considered in this study.

Non-electric Phenomena

Nerve impulses are not able to pass over the nerve trunk which is kept at a temperature a little above freezing. A test tube filled with ice water, for example, forms a very efficient block for experimental purposes.

The nerve impulse can not pass over the nerve trunk which is passed through a vessel containing carbon dioxide, or hydrogen, or nitrogen, or any other gas, to the exclusion of oxygen. Since oxygen is an essential factor in the passage of the nerve impulse, there must be some chemical action associated with the passing of the nerve impulse which is not to be considered in the discussion of the passing of an electrical current. Chloroform, ether, and other poisons efficiently block the passage of the nerve impulse. None of these can be considered as affecting the passage of the electrical current.

Fatigue

The nerve fibers seem not to be subject to fatigue, even after very long stimulation. Halliburton and Brodie stimu-

lated the splenic nerves of a dog for nine hours with an induced current, and upon the removal of block (a tube of ice water) the contractions of splenic muscle again occurred. No investigator has been able to demonstrate fatigue in nerves, except as their temperature should be greatly lowered.

The presence of carbon dioxide has not been certainly shown in the passage of nerve impulses over nerve fibers. It has not been shown that any rise of temperature is produced by the passage of the nerve impulse.

Initiation of the Nerve Impulse

Under normal conditions, nerve impulses may be initiated under most diverse conditions.

Sound waves cause the stimulation of the endings of the auditory waves, and this stimulation is qualitatively and quantitatively dependent upon the rate, and force, and combinations of the exciting vibrations. Light waves excite the rods and cones, and this stimulation is qualitatively dependent upon the stimulus. But in the case of color perception, the differences in vibratory rate affect the visual apparatus in such a way as to cause sensations which are qualitatively different, as red and yellow and blue, to result from the mere speed differences of the vibratory rates. In the case of taste, we have similar phenomena. Substances which are chemically and physically closely related, such as sugar and starch, have no relationship in taste, necessarily, while there may be great similarity in the tastes of substances whose chemical and physical relations are not at all alike. This is shown in the similar tastes of saccharine and sugar, of picric acid and quinine. Also, in the sense of smell there is not necessarily any qualitative relationship between substances which affect the sense in similar manners.

These facts are elemental, and do not depend upon any deceit in sensation. A certain deceit is shown in many ways.

as in the hungry feeling associated with dyspepsia, or the false judgments of sight, etc.; but in dealing with the simpler primary sensations we must realize that there is no essential relationship between the effect produced in consciousness or in reflex actions and the real nature of the thing which gives origin to the nerve impulses. In other words, there is no accounting for nerve impulses in terms of the original stimulation, except as these relations become known to us by experience and correlation during life.

Within the nervous system, upon the receipt of sensory impulses of whatever origin, there is aroused in other cells the physiological change associated with the passage of the nerve impulse. The sensory neuron of the second order is caused to initiate the nerve impulse by the effects produced upon it by the sensory neuron of the first order, and the nerve impulse thus initiated causes the stimulation of yet higher neurons, and thus the impulse is carried, through devious pathways, to the reflex and conscious centers. It is true that nerve cells may be caused to act by local conditions, such as the character of the blood flowing through the centers. In cases of tumors and other local conditions, also, the nerve cells may be directly stimulated. But for the most part the stimulation of the cells of the central nervous system depends upon the effect of the impulses from the sensory nerves, and from cells in relation to the sensory nerves.

The motor nerves carry the impulses, however produced, to the structures with which they are related. The effects produced by these impulses are almost as varied as are the stimuli which initiate the sensory impulses in the first place. Yet there is no more reason to impute differences in the nature of the impulses concerned to the motor than to the sensory nerves. It seems to be the function of the structures which the nerve impulses reach to transmit these into the activity peculiar to their own structure. The gland secretes its own

juices, the muscle contracts in its own manner, the cells are modified in their physiological condition by the nerve impulses in the manner in which their own peculiar function justifies.

Resume

The nerve impulse, then, represents an infinitesimal amount of energy. Its apparent activity is chiefly due to its causing the use of energy by other structures. It is associated with the production of electricity, but it is not electricity as we now understand electricity. It is associated with certain of the phenomena of metabolism, but it fails in other aspects of metabolic action as we find this action in other physiological activities. Nerve impulses must be essentially alike, yet the manner of their transmission, and even more the nature of their effects in consciousness, differ very widely.

The nerve impulse travels at very different rates, always much slower than does electricity. It is fastest in the higher animals, as a rule not without exceptions. Its rate is modified by disease, and by the physiological conditions of the structures which transmit it. Its production by the nerve cell is subject to practically infinite variation, both in different cells and in the same cell at different times.

The transmission of nerve impulses changes the cells affected in their physiological condition. The cells which to-day transmit an impulse of a certain origin and effect, to-morrow are somewhat more easily affected by similar conditions. This effect upon the condition of the nerve cell is permanent, and is probably the source of memory, as it is certainly the important consideration in the formation of habit.

Specific Nerve Energies

According to the "Doctrine of Specific Nerve Energies" of Johannes Müller, each sensory neuron arouses in consciousness its own quality of sensation and no other. For example,

the specific energy of each neuron in the chain leading from the ganglion spirale to the auditory area in the cerebral cortex is the sensation of sound; the specific energy in each neuron concerned in carrying impulses of touch is touch, and so on. There are certain facts of clinical and experimental evidence which support this view.

Stimulation of "cold spots" by the electric current give the sensation of cold, the same stimulation of another skin area may give the sensation of heat, of another area the sensation of touch, etc., while if the same electrodes are placed upon the zygoma or the mastoid, sensations of sound result; if they are placed upon the frontal bone, lights flash before the eyes; placed upon different parts of the tongue, different sensations of touch, pain and taste are perceived.

If any part of the brain be diseased or injured in such a manner as to stimulate the nerve cells of the cortex, sensations arise in consciousness which are the specific energies of the parts affected.

The aura of certain forms of epilepsy is frequently the specific energy of the part of the brain affected. This is so well recognized that surgical measures for the relief of this condition are usually successful in the sense of determining the nature of the disease, though not so often in the sense of securing recovery from the attacks. These facts seem to support the view that each neuron carries its own qualitative impulses and none other.

On the other hand, it is noted that the stimulation of nerve trunks, as, for example, a blow upon the ulnar nerve, never produces in consciousness exactly the same sensations as those aroused by stimulation of the sensory nerve endings in the fingers. Also, while stimulation of the optic and auditory nerves by other agents than light or sound is followed by conscious sensations of light or sound, these sensations are merely those of flashes of light and of snapping or rumbling

noises, but that exact sights or sounds of things can not be produced in consciousness, either by abnormal stimulation or as the effect of disease or injury. The appearance of a tree, for example, or the notes of a song are not to be produced in consciousness by any experimental stimulation of nerve trunks. Disease of the memory areas of the cortex may, however, be associated with the reproduction of sights, sounds, and other sensations long since experienced.

If the doctrine of specific nerve energies be true, it becomes necessary to determine whether the differences in the sensations aroused in consciousness by different sensory nerve stimulations is due to essential differences in the structure of the neuron, or to its characteristic end organs, or to the relations and connections of the cortical cells. That there are very great differences in the structure of the end organs is evident. But the fact that pathological stimulation of the cortex produces the same class of sensations as those aroused by the normal stimulation of the same area indicates that the determining factors in the production of the various sensations are not found in peripheral sensory neurons alone; unless, indeed, we ascribe to habit and education the association of the various sensations with the stimulation of the corresponding cortical areas. Were this true — that is, if there be no primary difference between the form of sensation aroused in consciousness by the stimulation of the cells of the temporal lobe and those produced by the stimulation of cells in the occipital lobe, it is difficult to see how the associations ever became formed in the first place. On the other hand, it is certainly no less difficult to conceive of the enormous number of differences in the metabolism of the various neurons which would be necessary if every form of sensation were produced each by its own special form of nerve impulse.

Should the doctrine of specific nerve energies hold true for sensory neurons, it should hold true for motor neurons

as well. It is well known that the stimulation of the nerve to a muscle causes the muscle to contract, while the same stimulation of the nerve to a gland initiates the characteristic secretion of the gland. The mode of action of the so-called inhibitors suggests one of the most puzzling problems in physiology.

Nature of Sensory Impulses

The sensory impulses, in themselves, are probably simply nerve impulses, not to be distinguished qualitatively from the other nerve impulses. The changes in the environmental conditions affecting the more or less specialized endings of the sensory neurons initiate the nerve impulse. This, being transmitted over the sensory neurons of the first, second and higher orders, initiates certain reflexes, and, in many cases, reaches the cortical neurons and arouses consciousness of a more or less specific nature.

The lack of any qualitative relationship between the sensations in consciousness and the qualities of the objects in the external world is very difficult of comprehension. It is true that in some cases there seems to be actual correlation between the sensations in consciousness and the thing which causes the sensation, as in the case of sound. Here the differences in vibration rate are associated in consciousness with changes in tone which are qualitatively relative to the changes in vibration rates. The sensory impulses aroused by changes of pressure, by resistance to effort, also give rise in consciousness to sensations which probably bear a qualitative relation to the things perceived. But the sensations aroused in consciousness by changes in the light vibrations are qualitatively different; it is not possible to think of green as being merely a "faster" shade of red, nor can we think of yellow as a "slow" shade of blue.

Substances which are alike chemically do not necessarily

taste or smell alike; sugar tastes not at all like starch, with which it is chemically related, but very much like saccharine, with which it has practically no chemical relationship whatever.

Intrinsically, heat is a matter of vibration rate. Nothing in our consciousness has ever been subjected to the stimulus of an object without heat. We know, then, not the lack of heat, but only degrees of heat. Yet in consciousness are two qualitatively distinct sensations, that of heat and that of cold. That is, from certain degrees of heat we receive sensations of warmth, and from other degrees of heat we receive sensations totally different in quality, and capable of arousing both reflex and conscious actions of a totally different quality.

The actual conditions of the external world are, then, not to be exactly perceived by our mentality under any conditions, except as we determine them by various scientific and mathematical methods. What we do perceive is the relation between the environmental changes and our own reaction to those changes. In the biological sense those changes in the external world which affect us at all affect us in such a manner as to initiate those reactions most adapted to the preservation of the life of the individual and the race. Actual truth as a mathematical proposition is as far from the biological concept as is the preservation of the lives of the weaklings.

CHAPTER III

RELATIONS OF NEURONS

The individual neurons are functionally related by means of certain arrangements of dendrites, axons, collaterals and cell bodies, which bring the protoplasm of one neuron into very intimate structural relations with the protoplasm of another. This structural relationship which makes the functional relationship possible is called "synapsis," from a Greek word which means "clasping." Synapses are formed in various manners in different parts of the nervous system, and are often very complex. In all cases studied so far the axon or the collaterals from the axon of one neuron transmit the impulses to the dendrites or to the cell body of another. Thus, the axons are cellulifugal and the dendrites cellulipetal in function.

The synapses of the neurons concerned in the more complex coördinations, especially in those controlling the autonomic functions, are so intimate, each neuron receives impulses from so many sources and sends impulses to so many other neurons, that the older views of Bethe and Golgi and Nissl, that the whole nervous system should be viewed rather as a syncytium than as a collection of individual cells, seems at first to be well founded. This appearance is noted with particular distinctness in the cell groups of the medulla, where are situated so many of the chief viscero-motor centers. Here

may be well seen the extremely delicate fibrillæ, resembling the extensions of the spongioplasm of the cell body into the pericellular space, which have aroused so great discussion. These fibrillæ may be traced from one cell to another in so many cases and with such exactness that the existence of protoplasmic bridges can not longer be denied. Yet in these same centers may be found other cells, placed near each other, which seem to have no structural relationships. It seems probable that in the viscero-motor centers, at least, those neurons which are most closely related in function are those whose synapses are most intimate and complex.

The synaptic relations of neurons are so varied that an almost infinite variety of reactions to any given environmental change becomes possible, as is, indeed, manifest to even the most superficial observation of the habits of the higher animals. Any one axon may give off a number of collaterals, all of which may form synapses with as many other nerve cells, and any one nerve cell may receive impulses from several different other nerve cells. When it is remembered that the nervous system contains thousands of millions of nerve cells, it is evident that the infinite complexity of even human thought and action does not surpass the complexity of the neuronic synapses.

Cord Synapses

Probably the simplest form of synapsis is that found in the gray matter of the cord, as well as in other parts of the nervous system. The entering fibers of the posterior roots, the collaterals from the fibers of the spinal white matter, the axons of the Golgi cells of Type II of the cord, all break up into a very fine feltwork which surrounds the intrinsic cells of the gray matter, the motor cells of the first order and the cells of the viscero-motor centers of the cord. (Fig. 17.) The dendrites of the cells just mentioned branch freely among

this complex feltwork, and by this means the impulses from several sources become able to affect the action of the muscles, the viscera, and the coördinating centers of the same and adjacent spinal segments.

Cerebellar Synapses

The Purkinje cells of the cerebellum display two very pretty methods of synapsis. The bodies of these cells are surrounded by a delicate network of collaterals from the axons of the stellate or basket cells of the cerebellum. This basket arrangement is similar to the feltwork around the spinal cells, but it is rather more easily visible and is more exactly limited to a single cell. (Fig. 18.) The dendrites of the Purkinje cells branch very freely in a manner resembling some old oak tree, except that the branches lie all in one plane. These dendrites are interlaced and wound around by fine vinelike "climbing fibers," as they are called, the prolongations of cells whose location is not exactly known, but which almost certainly are carried into the cerebellum by way of the peduncles. (Fig. 19.)

Olfactory Synapses

The olfactory lobes show another form of synapsis. The olfactory nerves entering the lobe pass tangentially over the surface for a variable distance. They then plunge into the mass of the lobe, giving off no collaterals; each axon branches and twines into a glomerulus. In the glomerulus also are found dendrites from the mitral cells of the olfactory lobe, which branch among the fibrillæ of the olfactory axons. By means of this structure each cell of the olfactory region of the nasal mucous membrane is able to transmit impulses to a mitral cell, which, in turn, sends impulses brainward. (Fig. 20.)

Fig. 19. Cross section of lobule of cerebellum of woman of about 30 years. Semidiagrammatic. 72 diameters.

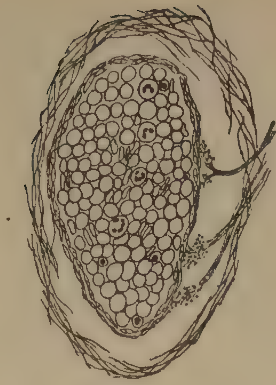


Fig. 21. Blood vessels of corpora mammillaria, human, adult. The vessel is filled with blood corpuscles. Around the vessel is a pericellular lymph space, which is enclosed by a layer of neuroglia. Three nerve endings lie upon the vessel's wall, 470 diameters.

Fig. 20. Olfactory lobe of kitten, 6 days old. Semidiagrammatic. 60 diameters.

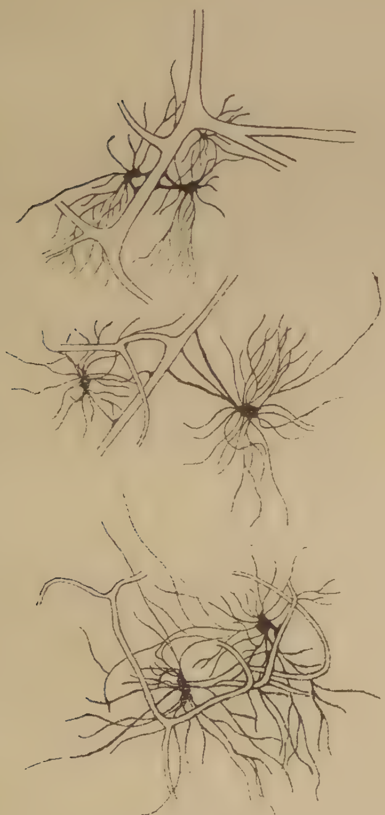


Fig. 23. Prodasteroids from medulla of adult cat. 60 diameters.

Fig. 22. Prodasteroids from cortex of occipital lobe of new-born baby. 175 diameters.

Amacrine Cells

In many parts of the nervous system are found cells, evidently nerve cells, which have freely branching dendrites, but for which no axons have been described. The function of these cells is not certainly known, but it seems probable that they are concerned in associating the nerve cells of their immediate neighborhood. Thus they would be similar to the Golgi cells of Type II in function. It may be, indeed, that the amacrine cells will be found to be of the same structure as the Golgi Type II cells.

Sympathetic Synapses

In the sympathetic ganglia each cell occupies a cagelike basket, which is formed of the interlaced fibers of the axons from the viscero-motor nuclei of the cord, medulla or midbrain. These small medullated fibers lose their sheaths near their termination and break up into the fibrillæ which make up the pericellular baskets of the sympathetic ganglia. Any one basket may be composed of several axons or collaterals, and any given axon may send collaterals into several baskets. (I have seen five branches from a single fiber which was medullated before the branches were given off.) It seems probable, also, that any one fiber from the viscero-motor centers may pass through two or more sympathetic ganglia, giving off one or more collaterals in each ganglion. The synaptic relations of the viscero-motor neurons are thus no less complex in the ganglia than in the spinal and medullary centers.

By means of the various methods of synapsis the neurons are able to affect the activities of one another and of the other parts of the body through the motor neurons of the first order. The nature of these effects are not yet well under-

stood. It seems evident that neurons may affect other neurons in at least two different ways.

Neurons may stimulate other neurons to increased action. This relationship is the most conspicuous. The stimulation of the sensory nerves may be followed by the passage of efferent impulses to the muscles innervated from the same spinal segment, or adjoining segments, or through the intermediation of the higher centers.

Neurons may inhibit the action of other neurons. This relation is not easily understood, but is evidently one of the physiological facts. The stimulation of the cortex inhibits the activity of the spinal centers. This is noted in the excess of reflexes of any area associated with the injury of the centers or tracts above the spinal segments innervating that area. The inhibition of one neuron or neuron group by another is a very important phenomenon in nerve physiology, and it is of especial importance in the consideration of those centers associated with consciousness. A temporary inhibition of any nerve center gives time for the receipt of nerve impulses from other sources to affect the ultimate reaction.

The nature of the inhibitions is not well known. There is some reason to assume a relationship between the phenomena of the refractory period and those of inhibition.

In the case of mankind the simplest possible reaction is that of the simple spinal reflex action. In this arc we may consider the possible existence of a single sensory nerve fiber in relationship with the pericellular basket of a single motor cell. It is evident that the stimulation of the sensory neuron can affect the activity of that motor cell, and that one only. It is not evident whether there might be at different times differences of the effect produced upon that cell by the receipt of the sensory impulse — that is, whether the physiological effects of the sensory stimulation might be subject to variation, as well as the liminal values of the two neurons concerned.

The more complex spinal reflexes depend upon the coördinate action of several neuron groups. It is evident that the interpolation of even a very few relay stations adds very greatly to the structural possibilities of the reaction which might follow upon the receipt of the sensory stimulus. Probably the simplest action of which we are capable, even reflexly, necessitates the activity of many nerve cells, extending through several spinal segments.

Another more complex arc includes in its circuit the spinal efferent and afferent cells, and the cerebellar centers. Reactions which are subject to the cerebellar coördinations are as complex as the habits which we learn, and which become as fixed as any reflex action whose foundations were laid in the nervous system long before birth.

Yet more complex are the arcs which include the cells of the centers lying about the base of the brain, in which the emotional and instinctive reactions are coördinated. In these centers are received, correlated, and sent out again, the impulses concerned in the movement not only of the skeletal muscles, but also of those visceral activities which have been found associated with the best and longest life of the individual and his race through all the phylogenetic developmental steps. Here are related in function the impulses concerned in the erection of the hair in fright, the grinding of the teeth in anger, the movements of the nose in disgust, and all the other phenomena of the instinctive and emotional reactions.

These various reflex arcs are complex; their action necessitates many coördinate reactions on the part of millions of nerve cells; their activities are the result of ages of inheritance of those whose nervous systems were adapted to performing their duties most efficiently, and through the working out of the many other laws which govern racial development. Yet all of these reactions appear very simple and predicable when the arcs which include the cerebral cortex are noted.

Receiving impulses from all parts of the body, the cortical centers coördinate and control the impulses arising from the activities of the lower centers. The impulses are also coördinated in relation to the past effects of previous experiences. Through the intermediation of consciousness, not only the actual past may be enabled to affect the ultimate reaction, but the elements of past experiences may be dissociated and recombined, in order that the ultimate reaction may be wise beyond experience — or foolish beyond experience, if the dissociations and the recombinations were ill advised. All of this multiplicity of reaction capacity and reaction choice becomes possible only through a multiplicity of synaptic relationships.

In any given neuron group, or neuron system, it appears that there must be an element of choice — not, of course, necessarily conscious. If any one neuron in synaptic relationship with two other neurons should be stimulated, it is evident that three different reactions are possible, excluding qualitative differences. The stimulation of the first may cause the stimulation of either of the two to which it is related, or it may cause the stimulation of both. If one neuron is associated with three or more others in function, the number of the possible reactions becomes increased to seven — the stimulation of any one of the three, of any combination of two out of the three, or of all three of the neurons. It is evident, then, that the element of physiological choice becomes a matter of some complexity.

So far as these relationships have been studied, the factors which determine the choice in any given case are as follows:

I. The impulses from any nerve cell are apt to be carried over the axon rather than over the collaterals from the axon. Thus, the impulses from the motor neurons of the cortex are carried directly to the lower motor centers, with-

out affecting the basal ganglia cells, unless the stimulation of the cortical cells be profound. In case of increased stimulation, the impulses are carried over the collaterals also, and, in most cases, more active movements result than is the case of the lighter stimulation.

II. Of two neurons in synaptic relationship with a third, that one which has the lower liminal value is the more apt to be stimulated. The factors which modify the liminal value of any neuron have already been discussed.

III. There is some evidence in favor of the view that the gemmules upon the dendrites of the nerve cells are capable of amoiboid movement. If this be true, it is possible that the retraction of the gemmules or of the dendrites may modify the receptivity of any neuron.

IV. There is, in nerve cells as well as in muscle, gland, and other active cells, a certain refractory period following stimulation, during which any stimulus received is followed by no perceptible effect. This refractory period is very short in the case of the nerve cell, but is demonstrable in so many instances that it is fair to assume it to be a characteristic of neuron physiology in general. If, of two neurons receiving impulses from a third, one has been so recently stimulated that the refractory period is not yet passed, the other is the more apt to be affected.

V. Impulses which arise from those parts of the body nearest the spinal cord are most apt to initiate deep-seated reflexes than impulses arising from structures more distant from the cord. This is doubtless due to the fact that the innervation of the body is determined at a time when the cord occupied a position somewhat more nearly the center of the structures innervated. The budding of the limbs and the changing form of the thorax and the abdomen modify the areas of innervation, and while the number of nerve cells and fibers becomes increased to a certain degree, the central rela-

tionships do not appear to be rendered more complex in correspondingly great degree. Thus we have the malpositions of the vertebræ, a source of greater ills than malpositions of the bones of the hands, for example. Irritation of the skin over the back of the neck may be a source of considerable reflex irritation, but the irritation of the skin over the arm or the foot has much less of an evil effect, so far as the deep reflexes are concerned.

VI. Sensory impulses are more efficient in arousing any given reflex action the more nearly the functional relation between the area stimulated and the area affected by the efferent impulses. The sensory impulses from any part of the naso-pharnyx, for example, are more apt to affect the other parts of the respiratory tract, producing a sneeze or a cough, than to affect the activity of the muscles of the pharynx, which are nearer anatomically but less closely related in function. Sensory impulses from the buccal pharynx, on the other hand, are more apt to initiate the reflex actions concerned in vomiting.

VII. Those impulses affect consciousness most vividly which arise from parts of the body most immediately affected by environmental changes. Impulses from the skin are clearly perceived in consciousness and are located with more or less accuracy. Impulses from those parts of the skin most subject to stimulation are those in which the localizing sense is most acute. Impulses from the skin of the back, for example, while fairly well adapted to the production of reflex effects, are not well localized in consciousness.

VIII. Other things being equal, those impulses arising from parts of the body whose nerve centers are being left behind in the process of cephalization, or which are themselves in process of phylogenetic regression, are least apt to affect consciousness, and are most apt to be efficient stimuli of the reflex activities. This is noticed in the case of the vestibular

sensations, which are scarcely to be recognized in consciousness even when the attention is given to the effort, yet which are very efficient in arousing reflex actions. The phenomena of seasickness probably illustrates this reaction, and also the phenomena of Meniere's disease. The centers for the area supplied by the lower sacral nerves seem to be in process of regression. The impulses from this part of the body are not especially well adapted to affecting consciousness, though injuries of them may cause extreme suffering, but even slight injuries of this area are often associated with reflex effects out of all apparent proportion to the sensory disturbance.

IX. Conscious attention to any sensory impulses increases the power of those impulses to affect consciousness. This phenomenon may add to the suffering under certain conditions of disease.

Other factors not yet studied are probably responsible for many of the inexplicable effects of stimulation. In the case of the peripheral irritations, for example, it is impossible to determine what effect will be produced in any given individual. The nature of the relations which make possible the inhibition of one neuron by another needs more study before our knowledge of the interneuronic relations is at all satisfactory. That these relations are capable of considerable modification seems probable from facts observed in certain clinic cases. The effects of cross suturing of nerves, both experimentally upon animals and in traumatic paralysis in man, seem to indicate that the permeable pathways of impulses through the central nervous system are capable of change. In locomotor ataxia, also, the results of careful re-education show that probably nerve impulses may ultimately employ pathways which, under normal conditions, would not be used. Many of these things are not to be explained satisfactorily with our present knowledge of the functional relations of the neurons.

CHAPTER IV

THE PHYSIOLOGY OF NERVE CENTERS

A nerve center is a group of nerve cells so related as to coördinate the nerve impulses which control any function. A nerve center may control any one organ, as the center of the sixth cranial nerve, or it may control a group of different organs, as the respiratory center, or it may control the functions of similar structures scattered over a wide area of the body, as the sweat center. Almost every imaginable degree of complexity of function and structure is illustrated in the nerve centers.

All nerve centers have certain characteristics and all lie within the central nervous system.

The nerve cells composing any center are very closely related in structure. This intimacy is accomplished in three different ways:

I. Golgi cells of Type II are found. The short and freely branching axons of these cells connect cells in function which lie near one another. Amacrine cells may be found in some centers.

II. Axons entering any centers, which bring to it the nerve impulses from other parts of the nervous system, give off collaterals to several cells of the center. Thus several cells are directly affected by the same entering stream of nerve impulses, and, through the mediation of the Golgi cells of Type II, this number is increased.

III. The axons from the cells of the center give off col-

laterals which branch freely and form synapses with other cells of the center. Thus the activity of any cell may affect the activity of other cells of the same center. The number of cells thus directly affected is great, in some cases at least, but through the cells of Type II the activity of still other cells is affected by the same relationship.

Centers which control the simple structures act by sending axons directly to the structures concerned in that function.

Centers governing complex functions act by sending impulses to lower centers, to inferior and simpler cell groups which directly control the structures concerned in that function. Several different cell groups of varying degrees of complexity may thus be concerned in the government of certain complex coördinations.

All centers are themselves subject to influence of other centers. We speak of "higher" centers, as if these were of authority. The term "higher" centers may be used in its structural sense, but only in a very restricted manner in its physiological sense. The centers which are higher are themselves as subject to the influence of impulses from the sensory and associational neurons as the lower centers are subject to the higher. In other words, the physiological activity of any center at any time depends upon the physiological condition of that center, and upon the algebraic sum of the nerve impulses which reach it from other parts of the nervous system. Ultimately, the source of all nerve impulses must be found in the incoming stream of sensory impulses which are derived from the changes in the conditions of the body to a certain degree, and to a greater degree from the changes in the environment of the body as a whole.

The physiological condition of the cells of any center depends upon several factors. The nutrition of the nerve cell varies under physiological as well as pathological conditions. The food supply is in the lymph which bathes the cell. If the

blood circulates too slowly, or if it contains less than the normal amount of nutritive substances, or if it is surcharged with the waste products of katabolism or with poisons either autogenic or otherwise, then the activity of the center is variously modified. In general, slight amounts of poison, or fatigue, or slightly increased blood pressure, or temperature, increase the irritability of the nerve centers. Greatly increased pressure or temperature, or larger amount of poisons in the circulating lymph, lessen the irritability of the centers, and thus decrease their action. In the case of the respiratory and heart centers, probably also in the case of certain centers of the lower thoracic cord, the presence of varying amounts of carbon dioxid in the circulating blood is an important factor in controlling the physiological activities of the functions controlled by these centers.

The physiological condition of any center depends in part upon its rest or fatigue. Nerve cells which have been resting, in which the tigroid masses are well formed and of angular outline, are normally irritable. If the cells have been active for so long a time as to cause a partial or complete disappearance of the tigroid substance, the activity of the center is lessened.

The past experiences of any center modify its physiological condition. Each time any cell or cell group is stimulated the liminal value is lowered, and its irritability increased. This lowering of the liminal value seems to affect the cell for its lifetime. Thus, any center which frequently is called into action becomes constantly more readily stimulated. Any center which is subjected to excessive stimulation becomes abnormally irritable. If the stimulation is long continued, especially in an abnormal manner, the ultimate loss of function may result and may be followed by structural injury. This condition is exemplified in those cases of transverse myelitis due to excessive and abnormal sexual activity.

The inactivity of any spinal center in the long-continued presence of bony malpositions or of the various peripheral irritations falls within this class of sources of abnormal action on the part of the nerve centers.

The nervous system is supplied almost exclusively by terminal arteries. The occlusion of any one by pressure or by thrombus or embolus, or in any other way, thus results in the complete loss of nutrition in the part supplied by that artery. The area of infarction undergoes degeneration. The loss of the function of the nerve centers thus affected is absolute. Only the assumption of this function by other nerve groups can secure a certain amount of compensation for the injury.

The nerve impulses reaching any center from other parts of the nervous system include impulses which stimulate the center to increased activity, and those which decrease its activity. These last are called inhibitory. The manner in which the inhibitory impulses act is not known, but it seems certain that there are impulses which do lessen the activity or the irritability of other nerve cells.

Nerve centers act in accordance with the physiological condition of their constituent neurons. This is more easily seen in the autonomic centers. While the neuron is alive it, like other cells, is engaged in the processes both of anabolism and katabolism. During the period of inactivity the anabolic processes are more active than the katabolic. After a time, then, the accumulation of the anabolic products leads to an increased irritability of the neuron. This increased irritability may, in the absence of stimulation, become so great that extremely minute variations in the environment of the neuron, or perhaps even without such changes, the katabolic activities are initiated. This suggests the condition of affairs found when a child builds a tower with his blocks. He may place one above another, and another above that, and another, and another, until the instability becomes so great that the addition

of a single block causes the destruction of the whole. Roughly, this may illustrate the phenomena of the action of the autonomic centers in the absence of stimulation reaching them. It must be remembered that this form of reaction is merely one of many — that the nerve centers rarely become so filled, or charged, with their anabolic products as to initiate the nerve impulse, because they are constantly subject, during anything like normal conditions, to the constant stream of stimulating impulses from other parts of the nervous system, and to the stimulation afforded by changing pressure of the blood and by changing characteristic of the blood itself.

The typical nerve center receives axons from other nerve cells as follows:

I. Collaterals from the axons of sensory neurons of the first order. By means of this relationship the center is enabled to act in accordance with immediate sensory impulses, and thus becomes a part of a simple reflex arc.

II. Axons and collaterals from sensory neurons of the second order. By this connection more complex reactions are coördinated.

III. Axons from other centers of related function. By this relationship it becomes possible for different centers to act synchronously, in a coördinated manner.

IV. Axons and collaterals from the axons from the basal ganglia. By this means the impulses concerned in the various emotional reactions, and those reactions concerned with those simpler forms of emotions called feelings, are enabled to affect the action of the centers

V. Axons and collaterals from the axons from the cerebral cortex. This includes both the axons from the central convolutions, by means of which volitional actions are produced, and also the descending axons from other parts of the cerebral cortex, whose manner of action is not known, but which may be concerned in the phenomena of attention.

VI. Axons and collaterals from the axons from the colliculi, from the pontine and olivary nuclei, from the vestibular nuclei, and from the cerebellum. The functions of these relations are not well known, but they may represent in part the relations important at an earlier stage of existence but now largely superseded by the development of the superior coördinations.

The recognition of the physiological condition of centers which seem to be acting in an abnormal manner is a matter of considerable importance to the physician, and especially to the osteopath. For if any center acts improperly it is always because of some abnormal effect which is being produced upon it from without. As the centers do not act of their own volition, whimsically, during health, neither do they act abnormally without cause. It is not conceivable that any center should fail to act in a manner as nearly normal as its structure and surroundings permit.

Nerve centers may act abnormally under the following conditions:

The original structure may be such as to preclude normal activity. Efforts at compensation and adaptation probably form the sum of the possible therapeutics in such deformities.

Sensory impulses of an excessive or deficient quantity may be sent into the center. The simple reflexes of which the center is capable may thus become either increased or decreased. If this condition continues very long, the liminal value of the neurons concerned may be so greatly lowered that later even normal stimulation may be followed by abnormal action. Visceral disease and subluxations of vertebrae and ribs are familiar examples of this condition.

The impulses from the basal ganglia may be affected by excessive emotional reactions, and the activity of the centers in connection therewith may thus become abnormal. This condition is especially true of hysterical subjects. In these

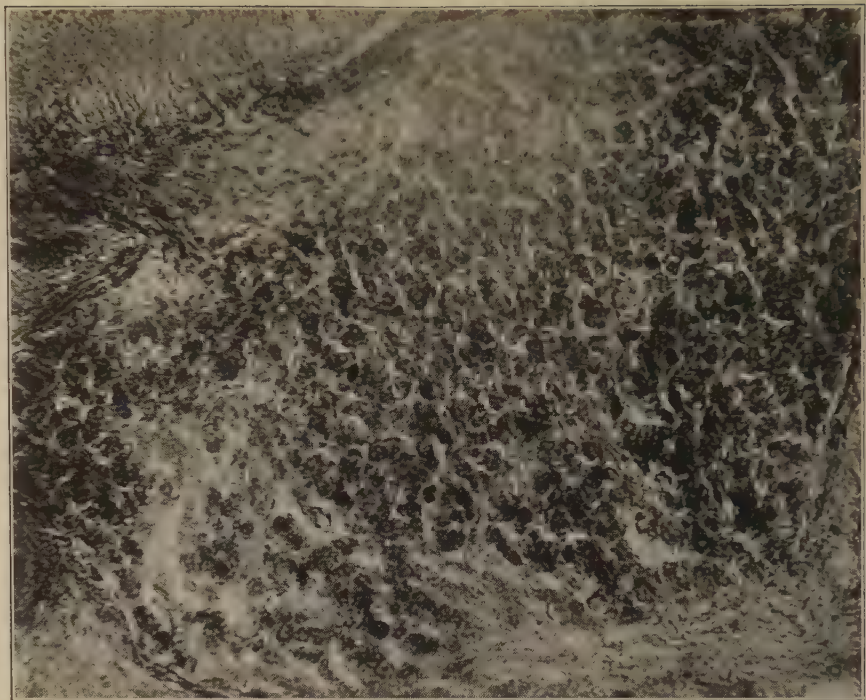


Fig. 24. Sensory ganglion of human embryo of about 10 weeks. Cells are small, round, with nuclei occupying almost the entire cell, and often eccentric. 200 diameters.

patients there is rarely any consciousness of the real nature of the condition. Often these cases require the most careful study in their diagnosis. And the care of such patients depends altogether upon the recognition of the stream of abnormal impulses descending from the basal ganglia to the lower centers.

Nerve centers may become abnormal in function because of the abnormal quality or pressure of the blood circulating through them. The place of the vaso-motor impulses in governing the nutrition of the cerebral and spinal centers is not yet very well known, but there is no doubt that these are important factors in controlling the circulation through the nerve centers, as well as through other organs of the body. Whatever renders the vaso-motor impulses abnormal must, then, affect the nerve centers to some extent.

It is essential for the normal activity of any nerve center that there shall be an unimpeded exit for the nerve impulses initiated by its activity.

Rarely the activity of the lower centers may be rendered abnormal by abnormal volitional impulses from the cerebrum. Since the volitional impulses are by their very nature temporary in activity, and since the reflexes which control the lower centers are more powerful as well as being practically omnipresent, this source of malfunction of the lower centers must be seldom encountered, if ever. But the persistent abuse of the lower centers through overwork or poisoning or in other ways is responsible for much of suffering and disease.

The proper treatment in cases of abnormal action of the nerve centers depends upon the recognition of the cause of the malfunction. In order to secure the recovery it is only necessary to see that the cells affected have rest if they need rest, exercise in due time and proportion, and the unimpeded flow of good blood flowing rapidly under normal pressure. Given these conditions, any nerve center not permanently injured

must ultimately become as nearly normal in function as its structural peculiarities permit.

Relation of Nerve Centers

In many instances the centers which have related functions are associated in the performance of those functions by means of neurons of association. The cardiac and vaso-motor centers, the cardiac and respiratory centers, are thus related. The nature of these relationships is not well known as yet. In some cases the connections are extremely complex, and in others it is only under decidedly unusual conditions that the physiological associations become recognizable. An examination of the sections taken from the medulla, for instance, shows each of the groups of nerve cells to be variously associated with other cell groups by means of axons and collaterals. It is true, also, that in other cases no association fibers can be demonstrated. It appears fairly evident that those centers which are most closely related structurally are, for the most part, those which have related functions.

The development of the nerve centers is rather complex. The facts known are comparatively few, yet it is possible to use those few facts in explanation of certain relationships which otherwise appear meaningless.

In the spinal cord of the lower vertebrates the gray matter is in great relative excess. With the higher development of the nervous system the process of cephalization is accompanied by the development of the long spinal tracts, and the gray matter thus becomes relatively less. In something of the same manner the process of cephalization leaves the centers of the medulla, pons, midbrain and cerebellum behind, with a relative diminishing of generalized functions and the assumption of more specific functions.

In certain instances the lower center thus left behind becomes atrophied or lost. This is noted in the case of the

vagal lobes, which are very important structures in the hind brain of fishes, but which are scarcely to be found in higher animals.

In the process of cephalization the ascension of the functions of the centers and tracts is not ever complete. Probably always there are left behind a variable number of connections with the lower centers, and a number of the associational structures by means of which the lower centers were enabled to perform their duties. Thus, although the functions of the lower centers are more or less completely superseded by the development of the higher, with their more specialized structure and their more highly differentiated functions, the lower centers retain much of their pristine relationships. These structures usually assume other duties, sometimes subordinate to the higher centers, as in the case of the superior colliculi, sometimes of quite a different function, as in the case of the nucleus dentatus of the cerebellum.

The complexity of the lower centers is more evident from the structural than from the functional standpoint. Many of the tracts of the medulla, pons and cord represent the structural relationships which are merely left behind in the process of cephalization, and which retain only a semblance of their one-time importance. The vestibulo-spinal tract, for example, was a tract of the greatest importance to the fishes; in mammals it is probably of the most minor import. In fishes it is concerned in the maintenance of equilibrium; in mammals it seems to be somewhat concerned with the maintenance of muscular tone, but its destruction by disease produces no perceptible symptoms.

The midbrain shows plainly this process of developmental readjustment. The colliculi in fishes and amphibia are not differentiated plainly into superior and inferior. Almost the whole of the roof of the midbrain receives indiscriminately the visual, auditory and cutaneous senses. With the

development of the centers of the thalamus, and still more of the cerebral hemispheres, these bodies assume different functions. The manner of their developmental changes can not be described here, partly for lack of space and partly because many of the steps are not yet well understood. It is enough for our present purpose that this development has occurred, that the colliculi become differentiated into superior and inferior bodies, that the superior developed the function of coördinating impulses to the eye muscles, while the inferior developed the function of coördinating the impulses to the ear muscles. The older functions of controlling the coördinations of practically the whole body's movements, of being concerned in whatever dim sensations of sight the amphibia and fishes are capable of, have been assumed by the higher centers. Yet the colliculi still receive fibers from both the medial and the lateral lemniscus, and still send fibers downward through the cord as the tecto-spinal tract.

The cerebellum was, in the beginning, simply the receiving center for the cutaneous sensations. With the disappearance of the lateral line organs, and with the development of the higher centers of the thalamus and the corpora striata, the functions of the cerebellum have been greatly modified. Yet the fibers carrying sensory impulses from the viscera, the somatic structures, and the sensory neurons of the second and higher orders still are carried to the cerebellum, and are of importance to it in the performance of its newer duties. The cephalization process is accompanied by the development of fiber tracts from the superseded centers to those of greater value in performing the duties. Thus, we have the complex by-paths of the sensory impulses by way of the anterior ascending cerebellar tract (Gower's tract), the brachium conjunctivum, the cerebellar cortex, the nucleus dentatus, the red nucleus, the thalamus and the cerebral cortex. This indirect

route is explicable only upon the recognition of the process of the phylogenetic development of the cerebellar relationships.

These instances are illustrative of the changes which have been recognized in the development of nearly all of the nerve centers of the medulla, pons and midbrain. The spinal centers seem to have been merely left behind in the race for supremacy; such functions as they retain show the original segmentation without such assumption of new functions as are to be seen in the centers named.

Associated with the cephalization of the centers is the development of the long tracts of the spinal cord, medulla, pons, midbrain, and hemispheres. The connections between the lower and the higher centers thus become a matter of great convenience.

These long tracts are the more subject to disease, partly, no doubt, because of their more recent phylogenetic development and their associated relative higher differentiation, and partly because of the fact that the longer tracts are made up of axons which are, because of their great length, separated from their cell bodies and the nuclei which control their metabolism.

In the presence of abnormal conditions of the central nervous system the existence of the relationships phylogenetically ancient may be of considerable importance.

We live at this time in an age of great convenience. We talk by telephone, send telegraph letters at night, expect to ride in airships, turn on light, heat or water at will in our homes, speak to many people through printed pages, and in many other ways we magnify our own personality by compelling natural forces to be part of our means of expressing our own individuality. Now, if any of us were placed in the forest, we could carry our own water, cook food, build our own camping places, and manage to exist fairly well. We

could not send messages rapidly, but we should be glad of the pony express if the wires were down and the railroads ruined.

Now, in much the same way the injury of the higher centers and the degeneration of the long tract leaves the patient without the use of the comforts of recent and more civilized development. But that is no reason for refusing to employ the centers which remain normal, if there be any such. The lower centers, the shorter tracts, are often left uninjured in the presence of quite extensive degenerations of the long tracts. When this is the case the education of the phylogenetically older centers and their related shorter tracts may be accomplished with much good to the patient.

In cases of locomotor ataxia, for example, the degeneration of fasciculus gracilis, and sometimes part of the fasciculus cuneatus, is fairly complete. Yet the shorter tracts, carrying impulses of temperature, pain, and a certain amount of the tactile sense, remain for a long time in a fairly normal condition. These shorter tracts with their centers may be educated until they become functional in a degree sufficient to enable the patient to perform many acts not otherwise possible. Probably the speedy and efficient coördination of the normal nervous system can never appear, but the partial use of the lost functions is something. This education must proceed along the same lines as other methods of education. The liminal value of the centers yet active must be lowered by very carefully studied exercises. It must be remembered that overuse of any nerve center increases its liminal value, and that the same causes which led to the destruction of the longer tracts and the more highly developed centers may affect the shorter tracts and their centers also. So the exercises must be kept within the limits of fatigue always. The interest and attention of the patient secure the passage of the nerve impulses from the higher centers of the brain to the lower centers, and this stimulation lowers the liminal value of all

the neurons concerned in the performance of the actions decided upon.

The patient with locomotor ataxia may, for example, be set to use his feet in the normal position. The tendency is for the feet to be excessively rotated externally. Let him sit in his chair, pushing the feet forward with the toes straight forward, then withdraw them, watching them and guiding carefully every movement. Other exercises vary with individual patients. Thus the centers remaining normal may be educated to take up the duties of the injured centers and the short tracts may carry the impulses necessary for the performance of many duties. Such exercises may be used in many abnormal nervous conditions.

This assumption of the duties long lost by the lower centers may interfere with diagnosis of cases of slow degeneration of certain nerve centers. This is evident in the light of experimental evidence. When the cerebellum, for example, is removed by several successive operations, the total loss of both hemispheres may be secured without the occurrence of any very noteworthy symptoms. This is, no doubt, due to the fact that the associated centers take up the work of the lost parts, and that they are able to do this because the slowly produced injury gives opportunity for the other centers to receive and send out the needful stimuli often enough to lower their liminal value, secure the permeable pathways in this way, and thus bcome functional. In case of diseases of the cerebellum, it may be that cases present no symptoms referable to the cerebellum at all, and only at autopsy is the real condition recognized. Probably in such cases the same assumption on the part of other centers through the slowly developing degeneration is responsible for the lack of symptoms. Similar conditions may be found in connection with all, or nearly all, of those centers which have undergone considerable changes in function during phylogenetic development. The condition

is not usually true of those centers whose functions have remained unchanged during phylogenetic development, or in those whose functions are of comparatively recent origin. Even in the case of speech, however, the loss of the speech center on one side of the brain may be followed by the development of the speech center of the other side of the brain. In this case it is not a matter of the assumption of the ancient duties by the centers originally active in those duties, but it is the new development of the brain areas not before functional, either in ontogenetic or phylogenetic development.

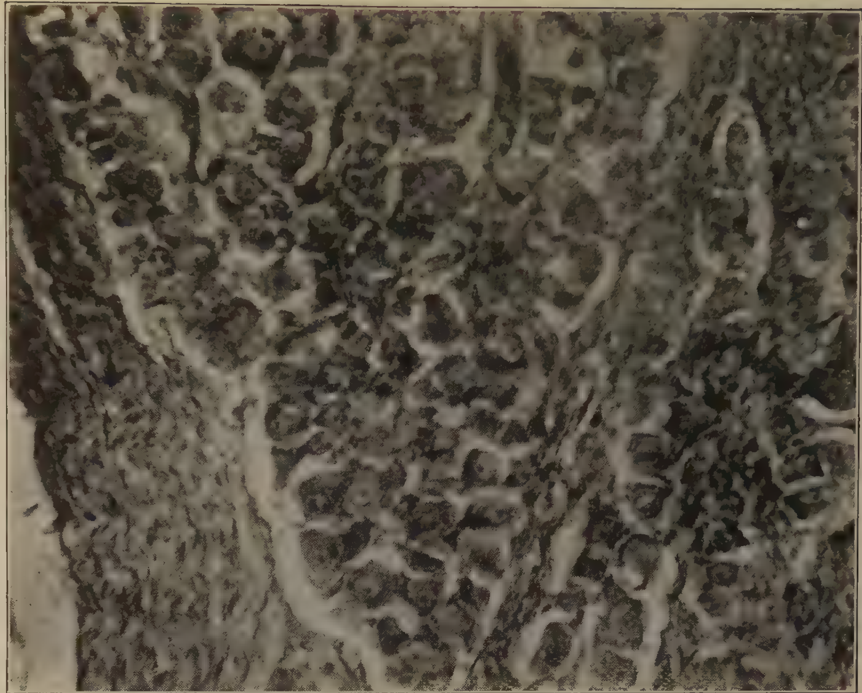


Fig. 25. Sensory ganglion of human embryo of about 5 months. Cells larger, protoplasm increased, dendrites beginning to appear, nuclei less eccentric. 200 diameters.

CHAPTER V

THE NUTRITION OF THE NERVOUS SYSTEM

Neurons are nourished by the lymph which bathes them, and the lymph is derived from the blood circulating through the vessels. The central nervous system and the sensory and sympathetic ganglia are alike in the lack of lymphatic vessels. In every case, in mammals, the nerve cell lies surrounded by a pericellular lymph space, and it is thus bathed on every side by the nutrient lymph. The whole extent of the neuron, to the ultimate extremity of its finest dendrite, is so placed as to enable it to perform to the best possible advantage those functions of absorption of foodstuffs and elimination of wastes upon which the normal conditions of metabolism depend. The lymph is drained from the nervous system by perivascular lymph channels. Both veins and arteries are surrounded by these lymph channels, but no lymphatic vessels are found elsewhere. Thus arose the older idea that the brain contained no lymph.

The arterial supply of the cord is very plentiful. The two posterior spinal arteries and the anterior spinal artery extend through the length of the cord, and receive with each nerve root branches from the cervical, lumbar or intercostal arteries. The anastomosis of these arteries is complex and efficient. It is not conceivable that any vertebral lesion short of actual crushing could bring about a diminution of the arterial supply to the cord through direct pressure. The effects

upon the spinal circulation indirectly produced through vasomotor impulses may be discussed at a later time.

From these longitudinal arteries and their anastomotic branches arise the arteries which enter the cord. These smaller arteries are of two classes, centripetal and centrifugal. Both sets are composed of terminal arteries, thus no anastomosis is found within the cord; there is, however, a certain amount of overlapping of the areas of distribution of the vessels.

The centrifugal arteries arise chiefly from the anterior artery. The branches enter the cord by way of the anterior fissure. They break up into fine branches which supply the gray matter, for the most part, though a few small branches supply the white matter in the immediate neighborhood of the centrifugal system.

From the posterior arteries arise a few branches of the centrifugal system also. These enter the posterior median septum and are distributed to the posterior white matter and to the central gray matter.

The centripetal arteries arise from both the anterior and the posterior longitudinal arteries. The branches from these pass around the cord, break up into finer terminal branches, and enter the cord at right angles to its surface. These finer terminals supply the white matter of the anterior and lateral funiculi, and in part the posterior funiculi. The white matter is less richly supplied with arteries than the gray.

This double arterial supply presents no explanation. That some clinical significance is attached to this vascular supply appears apparent when one remembers the frequency with which lesions of the gray matter are found without any apparent disturbance of the gray matter, and how often the gray matter is diseased without there being any recognizable lesion of the white matter. This clinical phenomenon may, of course, be interpreted otherwise than by artery supply.

Both centrifugal and centripetal arteries are supplied with vaso-motor nerves, which seem to be derived from the sympathetic ganglia of the same or adjoining segments. It is not known whether the centrifugal and centripetal arteries have identical vaso-motor innervation. It is very evident that the disturbances which interfere with vaso-motor impulses to the viscera, skin, etc., may also interfere with the vaso-motor impulses to the corresponding spinal areas.

The veins of the cord are very plentiful. The fissural veins drain the areas of the centrifugal arteries, while the root veins and the smaller veins emerging from the surfaces drain the areas supplied by the centripetal arteries. All of these veins unite in forming the spinal venous plexus. This plexus is made up of freely anastomosing veins. They have been rather vaguely divided into six longitudinal veins, but the anastomosis is so rich and the variations are so many that it is difficult to trace them as exactly six through the extent of the cord. This venous plexus is drained into the vertebral, lumbar, sacral, and intercostal veins. The veins of the central nervous system, including the spinal cord, are without valves.

The vessels of the medulla and pons resemble those of the cord. The vertebral arteries unite to form the basilar. From the two vertebrals below their union, from the basilar, and from the anterior and the posterior spinal arteries the arteries of the medulla and pons are derived. They may be divided into three sets. These sets are composed of terminal arteries, though their areas of distribution overlap to a certain extent.

The median arteries pass through the substance of the medulla and pons, and divide into fine branches distributed to the nuclei of the cranial nerves. The beginnings of the nerve roots also are partly supplied by the median arteries.

The root arteries enter the medulla and pons with the nerve roots. They include central and peripheral branches. The former are distributed with the median arteries to the

nuclei of the cranial nerves, the latter are distributed to the white matter in the neighboring areas.

The lateral medullary and pontine arteries pass around the external surface, and are distributed to the olives, the restiform bodies, and the pyramids. Branches from the inferior cerebellar arteries are distributed to the restiform bodies and the formatio reticularis.

The veins of the medulla and pons follow the arterial arrangement for the most part, and are drained into the superior and inferior petrosal sinuses or into the basilar plexus.

The cerebellum is furnished by three arteries on each side. The superior cerebellar is derived from the basilar. It is distributed to the superior surface. A small portion of the posterior border escapes from the supply of the superior cerebellar, which supplies also the geniculate bodies, the quadrigerminates, the tela choroidea, a part of the third ventricle, and sends some branches to the posterior surface of the pons.

There are two inferior cerebellar arteries, the anterior and the posterior. The anterior is from the basilar, also. It is distributed to the inferior anterior aspect of the cerebellum and the anterior inferior border.

The posterior inferior artery is given off from the vertebral artery before it unites with its fellow to form the basilar. The posterior inferior cerebellar artery supplies the medial part of the hemisphere, the inferior part of the vermis; it communicates with the superior cerebellar artery upon the posterior superior surface. There is a fairly free anastomosis among the larger branches of the three cerebellar arteries.

The cerebellar veins are called by the same names as the arteries. The internal cerebellar veins empty into the superior and inferior veins. The superior veins empty into the great cerebral veins, for the most part, but several smaller veins associated with these empty into the superior petrosal sinus.

The inferior veins run upward into the transverse or

straight sinus, or into the inferior petrosal and occipital sinuses.

The circulation through the brain presents many peculiarities. The vertebral arteries unite to form the basilar, the basilar unites with the internal carotids by way of the posterior communicating arteries, the anterior cerebral, from the internal carotid passes forward, and the left is united with the right by means of the anterior communicating artery. Thus a complete circle is formed which surrounds the brain stem. From this arterial circle (circle of Willis, in the old naming) the arteries are derived which supply the brain, and this circle is practically the last anastomosis of these arteries. There is a certain amount of overlapping in their areas of distribution, but no anastomosis.

The brain is supplied with blood by two distinct systems, the ganglionic system and the cortical system. There is very little overlapping in the areas of distribution of the two systems. Between them lies an area of the brain which is poorly supplied with blood, and this area is subject to the diseases of malnutrition in the aged or in those in whom any cause of enfeebled cerebral circulation is found.

The ganglionic arteries are small. They are distributed for the most part in an efferent manner, and supply the base of the brain and the basal ganglia.

They include the antero-median and the postero-median, the right and left antero-lateral and the right and left postero-lateral. Thus there are six chief arteries which, with their branches, compose the ganglionic system.

The antero-median is a branch of the anterior cerebral. It supplies the region of the optic chiasma, the rostrum of the corpus callosum and the head of the caudate nucleus.

The antero-lateral arteries are derived from the middle cerebral. They are distributed to the optic thalamus, the corpus striatum and the internal capsule. One of the branches,

the lenticulo-striate, is of interest because of its liability to hemorrhage in elderly people or in those subject to arterosclerosis. It is called the "artery of cerebral hemorrhage" for this reason. Since it supplies the striatum and the internal capsule, the paralysis which results from this hemorrhage is very widespread and is contra-lateral.

The postero-lateral arteries are from the posterior cerebral. They supply the posterior parts of the thalamus, the geniculates, the quadrigeminates, and the pineal body. These areas overlap the area of distribution of the superior cerebellar artery to a certain extent.

The postero-median artery is derived from the posterior cerebral and the posterior communicating arteries. It supplies the medial parts of the thalamus and the third ventricle, the cerebral peduncles and the space between the peduncles.

There are two choroidal arteries, an anterior and a posterior. The anterior arises from the internal carotid and follows the optic tract to the inferior end of the choroidal fissure. It supplies the choroid plexus of the inferior horn of the lateral ventricle, and gives collateral branches to the optic tract and to the hippocampus and hippocampal gyrus, the dentata, crus of the fornix, and posterior part of the internal capsule.

The posterior choroidal include two or more arteries on each side. These arise from the posterior cerebral and they pass forward in the transverse and choroidal fissures to be distributed to the choroid plexuses of the third and lateral ventricles.

The cortical arteries are those which supply the cortex of the hemispheres. These arteries give off a few branches which supply the ganglionic system, but after these few branches are lost no further relationship between the two systems is evident. Not only is there no anastomosis between the two systems, but there is almost no overlapping of their areas of distribution.

The anterior cerebral artery arises from the internal

carotid. It passes forward toward the longitudinal fissure, and the right anterior cerebral is joined to the left anterior cerebral by a very short anastomotic branch, the anterior communicating artery. The antero-median ganglionic artery arises from the anterior cerebral. There are four branches of the cortical system from the anterior cerebral, the anterior, middle and posterior internal frontal arteries, and the internal orbital artery. The anterior internal frontal supplies the anterior part of the gyrus cinguli and superior frontal gyrus on the medial aspect of the brain, and the superior and middle frontal gyri on its outer aspect.

The middle internal frontal artery supplies the middle part of the gyrus cinguli, the paracentral lobule, the upper part of the superior frontal and the precentral and postcentral gyri.

The posterior internal frontal artery supplies the corpus callosum, the posterior part of the gyrus cinguli, of the paracentral lobule, the precuneus, and the superior parietal lobule.

The internal orbital artery supplies orbital gyri, the optic chiasma, the olfactory bulb, tract, the roots of the olfactory tract, and the parolfactory area.

These four arteries are distributed to the cortical area as far posteriorly as the occipito-parietal sulcus.

The middle cerebral artery is the largest branch of the internal carotid, and it receives the direct current of its blood stream. Since the left internal carotid receives the most direct current of the blood stream from the ascending aorta, the middle cerebral artery is more apt to receive foreign substances carried in the blood stream than in any other artery in the body. For this reason the area of distribution of the left middle cerebral artery, and especially its ascending frontal branch, is apt to suffer from embolism. Since this area includes the kinesthetic area of the cortex, the embolus in this region results in a contra-lateral paralysis.

The middle cerebral artery (Sylvian artery) runs in the lateral fissure of the cerebrum (Sylvian fissure). It gives off the antero-lateral artery, and opposite the insula (Island of Reil) breaks up into six terminal branches.

The lateral orbital (inferior external frontal) is distributed to the anterior and posterior orbital gyri and the inferior frontal gyrus).

The ascending frontal includes two chief branches, which follow the central sulcus (fissure of Rolando) as far as the precentral sulcus, then follows this to supply the anterior central gyrus and a part of the middle frontal gyrus.

The ascending parietal is distributed to the posterior central gyrus (ascending parietal convolution) and the neighboring superior and inferior parietal lobules.

The parieto-temporal arteries include three chief branches. Two of these are distributed to the superior, middle and the upper part of the inferior temporal gyri. The posterior branch follows the posterior ramus of the lateral cerebral fissure (fissure of Sylvius) to its termination. It then divides into two branches, one of which passes upward to the supramarginal, post-parietal and angular gyri, while the other supplies the posterior part of the temporal lobe.

The right and left posterior cerebral arteries are formed by the division of the basilar arteries. They are joined to the internal carotids by the posterior communicating arteries. The posterior cerebral arteries give off the postero-median and the postero-lateral ganglionic arteries, and two or more posterior choroidal arteries. Its cortical branches are three, the occipito-parietal, the calcarine, and the temporal.

The occipito-parietal supplies the cuneus, preçuneus, and the superior occipital gyrus.

The calcarine artery supplies the cuneate and lingual gyri, the lateral and superior gyri of the occipital lobe.

The temporal branches are three in number, the anterior,

middle, and posterior temporal branches. These are distributed to the gyrus hippocampus, the fusiform gyrus, and the inferior temporal gyrus.

The arteries described lie upon the surface of the brain. From them arise many very fine terminal arteries which penetrate the brain and are distributed to its gray matter. These arteries do not penetrate very deeply into the brain, and the white matter receives most of its comparatively scant blood supply from the ganglionic system.

The arteries of the brain are now known to receive vasomotor nerves from the sympathetic system. (Fig. 21.) The fibers arise as white rami from the upper thoracic segments of the cord, and pass with the sympathetic chain to the superior cervical ganglion. Here the medullated fibers terminate by entering into the formation of the superior cervical pericellular baskets. The axons of the sympathetic cells pass by way of the carotid plexus to the arteries of their distribution.

Certain neuroglia cells, called "podasteroids," seem to be concerned in the nutrition of the brain. These cells lie along the pericellular lymph spaces, partly inclosing them, and partly supporting the blood vessels, especially the capillaries. These podasteroids send prolongations to the walls of the vessels, and rest upon them by a footlike expansion. (Figs. 22, 23.) Under certain abnormal conditions, such as hemorrhage, poisoning, etc., the podasteroids are found to be swollen and the footlike expansions are filled with debris, bits of blood clot, etc.

It is, however, probable that the most efficient regulation of the cerebral circulation is through changes in the general blood pressure. The brain is inclosed in the dense skull, the brain itself is almost fluid, the lymph and blood are fluids, and therefore the cranial contents are practically noncompressible. Vaso-constriction or vaso-dilation of the cerebral vessels must, therefore, be less efficient in modifying the cerebral circulation than are changes in the systemic blood pressure. This is

most efficiently modified by variations in the splanchnic circulation, by variations in the heart beat, and by variations in the pulmonic blood supply.

The veins of the brain have several peculiarities. They have no valves. They are enclosed in bony channels called sinuses. They are surrounded by perivascular lymph spaces. They are very large in proportion to the arteries whose blood they receive. They have very free anastomoses. The veins empty at a recurrent angle. The veins of the skull have many pouchlike diversions. Enissary veins through the skull assist in preserving a constant intracranial pressure in the presence of variations in the systemic pressure and of overfilling of the cerebral vessels.

The sinuses are formed by folds of the dura mater. They are lined with endothelium continuous with that of the vascular system as a whole. The sinuses are as follows:

The superior sagittal sinus (superior longitudinal sinus) extends from the foramen caecum to the confluens sinuum (torcular Herophili). It lies in the triangle formed by the inner layer of the dura mater as it dips into the longitudinal sinus, and the outer layer of the dura as it remains attached to the skull. This sinus receives the blood from the superior cerebral veins, the diploe, the dura mater, and, in its posterior portion, from the pericranial tissues.

The inferior sagittal sinus (inferior longitudinal sinus) lies in the fold made by the dipping dura as it is folded back upon itself at the inferior or free edge of the falx cerebri. It terminates in the straight sinus. It receives the veins of the falx cerebri, and sometimes a few from the mesial surface of the brain.

The straight sinus lies in the triangle formed by the two layers of the falx and the tentorium cerebelli. It terminates at the confluens sinuum (torcular Herophili).

The occipital sinus lies in the angle of the attached

margin of the falx cerebelli as the superior sagittal sinus lies in the angle of the falx cerebri. It communicates with the spinal veins and terminates in the confluens sinuum.

The transverse sinuses arise from the confluens, and pass outward in the triangle formed by the tentorial fold of the dura and the skull. At the base of the petrous portion of the temporal bone the superior petrosal sinus empties into the lateral sinus. It then communicates with the occipital sinus, and unites with the inferior petrosal sinus to form the internal jugular vein.

The cavernous sinus lies along the side of the sella tursica. It is a continuation of the ophthalmic veins, and receives the blood of the spheno-parietal sinus, a small sinus which follows the posterior border of the lesser wing of the sphenoid bone. The right and left cavernous sinuses are joined by the anterior and posterior sinus intercavernouses.

The cavernous sinus terminates by dividing into the superior and the inferior petrosal sinuses. The termination of the superior petrosal in the transverse sinus has already been mentioned. The right and left inferior petrosal sinuses are joined by the basilar plexus of veins, and unite with the lateral sinus to form the internal jugular veins.

CHAPTER VI

THE SENSORY CONDUCTION PATHS

In order that the body may react to its environment in a manner which preserves the life of itself and its race, it is necessary that provision be made whereby the changes in the body itself and its environment may, either directly or indirectly, affect motor structures. In the case of the human being this relationship must include the consciousness of at least a part of the environmental and bodily conditions. This need for a functional relationship between the motor structures and those parts of the body most easily affected by external changes is met by the sensory neurons, the motor neurons, and various associational neurons by means of which the various impulses from different parts of the body and from different sense organs are coördinated. The essential features of this function are: first, some form of peripheral structure capable of being affected by some character of environmental or bodily change; second, a nerve fiber and nerve cell capable of transforming the stimulus thus received into a nerve impulse; third, central relationships capable of transmitting these nerve impulses to the motor neurons; fourth, efferent neurons; fifth, motor structures capable of being affected by the nerve impulses transmitted to them. (Figs. 24, 25, 26, 27.)

The Functions of Sensory Impulses

Sensory impulses form the foundation of all nervous activity. Practically every reaction to external or internal changes depends upon the transmission of sensory impulses

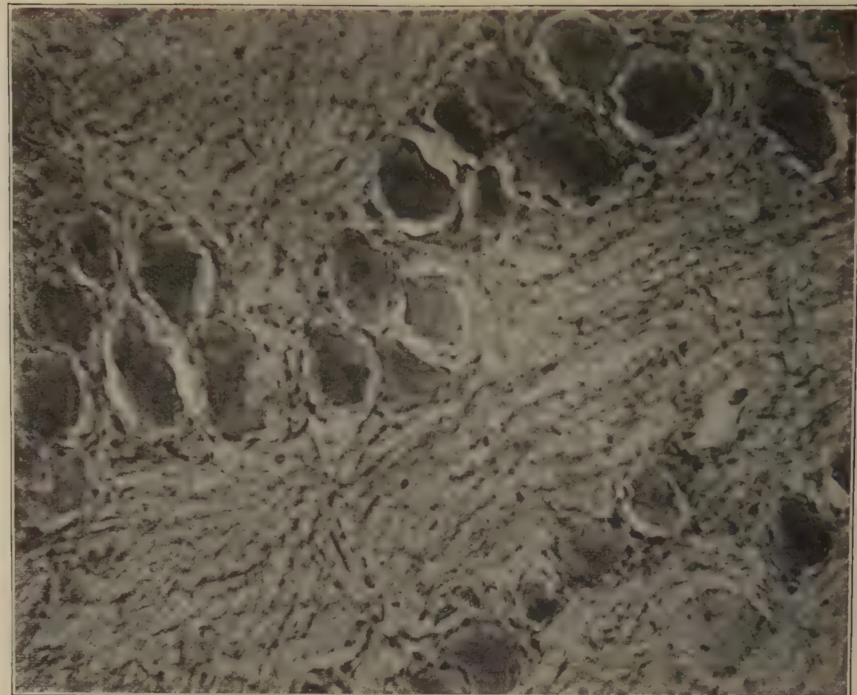


Fig. 27. Sensory ganglion, adult dog. 200 diameters.

aroused by these changes into the central nervous system. Mentality and volition are dependent upon sensory stimulation; the effects of any given sensory impulse may be immediate or may be long retained within the nervous system. But ultimately practically all efferent impulses are derived from precedent afferent impulses.

Sensory impulses may initiate impulses to the skeletal or the visceral muscles or glands. These may pass over the simplest path, by way of the collaterals to the anterior or lateral horn cells, or they may follow more complex paths involving almost any number of neurons. The relation which the outgoing impulses bear to the incoming impulses depends upon the structural relationships of the neurons concerned, and upon the comparative liminal values of these neurons.

Stimulation of the somatic sensory nerves of any segment of the cord may affect the activity of the skeletal muscles, the visceral muscles, the blood vessels, and the glands innervated from the same segment, either directly or by way of the sympathetic ganglia.

Stimulation of the visceral sensory nerves of any segment of the cord may affect the same structures, according to the structural relationships and the comparative liminal values of the associational and motor neurons.

The physiological value of these reactions is apparent. By means of the reflexes thus dependent upon the sensory impulses the repair of wounds is facilitated, rest of any injured part of the body is compelled, vaso-motor and visceromotor impulses are governed in accordance with the needs of the body under slightly abnormal conditions, and adaptation and compensation are facilitated under those conditions in which recovery is impossible. These same reactions may, however, become a menace in the presence of long-continued sensory irritation, as in the habitual use of abnormal foods, slight malpositions of structural tissues, or any of the various

peripheral irritations, such as eye strain, scar tissue in certain parts of the body, etc.

The sensory impulses which are carried to the higher centers have no less importance in the bodily economy. The viscero-motor centers in the medulla depend in great part upon the sensory impulses carried by way of the long and the short spinal tracts, by the vagus and other sensory cranial nerves, and by the descending impulses from higher centers themselves ultimately dependent upon sensory impulses.

Coördination is secured through the action of the cerebellar cells, which depend in like manner upon the sensory impulses carried by the ascending cerebellar tracts, the impulses from the cranial sensory nerves, and the descending impulses from higher centers which also are ultimately dependent upon the sensory impulses.

Sensory Neurons of the First Order

Sensory neurons of the first order are those which are immediately affected by changes in the environment of the body, or by changes in the condition of the body tissues.

It is not now possible to state how the environmental changes are able so to affect the sensory nerve endings as to initiate a nerve impulse. Since so great variations exist between the specific sensory nerve endings, it appears probable that the key to this problem may be found in a study of the structures and metabolism of these structures.

A number of the varieties have been illustrated, but no study has yet been made of their metabolism, apart from the metabolism of the neuron. Very little attempt has been made to classify the nerve endings from a functional standpoint.

Structure of the Spinal Ganglia

There are thirty-one pairs of spinal sensory ganglia, and two pairs of rudimentary coccygeal ganglia. These ganglia are placed upon the posterior roots of the spinal nerves, and

Fig. 28. Sensory ganglion, human embryo, 10 weeks. Cells chosen are most advanced. 470 diameters.

Fig. 29. Sensory ganglion cells, human embryo, 5 months. Cells chosen are most advanced. 470 diameters.

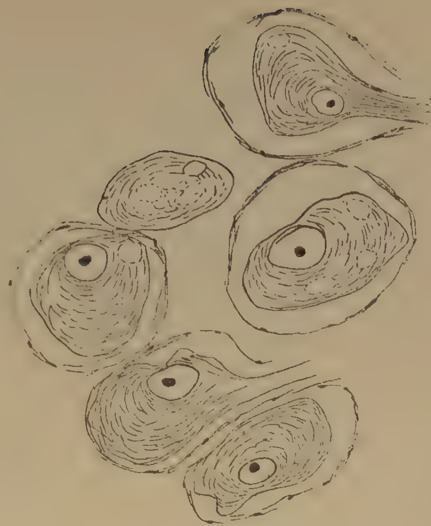


Fig. 30. Sensory ganglion cells of adult dog. The nerves from this ganglion had been stimulated by intermittent current of electricity for about ten minutes during anesthesia before death. The protoplasm is vacuolated, the nucleoli shrivelled, the nuclei either swollen or shrivelled, the pericellular lymph space is larger than normal, the tigroid masses have disappeared. 380 diameters.

Fig. 31. Section through cervical enlargement of adult dog Semidiagrammatic. Anterior aspect is upward. The posterior root fibers enter the cord and form synapses with the cells of the anterior horns. 10 diameters.

are situated within the corresponding intervertebral foramina. They are supplied by blood vessels from the corresponding veins and arteries, and the caliber of these vessels is controlled by vaso-motor nerves from sympathetic ganglia of the same or adjacent segments.

The ganglion is enclosed within a tough connective tissue sheath which is continuous with the perineurium of the nerve trunk.

The structure of the sensory ganglion is not so simple as was originally supposed. Two types of nerve cells are certainly known to be present in these ganglia, and others have been described by various authors.

The first of these types is that which was formerly believed to make up the whole of the nervous portion of the ganglion. (Figs. 28, 29.) It has a large cell body with many fine dendrites and a single process which arises from an axon hillock. At a variable distance from the cell body, but within the ganglion, this process divides into two branches, one of which passes to the periphery and terminates in a sensory nerve ending, while the other proceeds to the cord and enters into various relationships to be described presently. These cell bodies lie within a pericellular sheath of connective tissue. A space is always to be found between the sheath and the cell body, which may be an artifact, or may be normally filled with lymph during life. This space is left larger than normal by the shrinking of cell body in fatigue or during certain abnormal conditions. (Fig. 30.)

Another type of cell found in the spinal ganglion is that called after the name of Dogiel. It has many fine dendrites, and a short axon which breaks up into fibrillæ within the ganglion. These fibrillæ form basketlike networks around the other cell bodies of the ganglion, including those already described. These resemble in structure the Golgi cells of Type II, and probably they have similar functions.

Amacrine cells also have been described in the spinal ganglia.

Other cells have been described which have small cell bodies and relatively large nuclei which stain deeply. Thus they resemble embryonic cells. Nothing is known of their function. Some writers describe non-medullated nerve fibers from these small cells entering with the posterior roots of the cord.

The nerve trunks seem to consist chiefly of the processes of the group of cells first described. The posterior roots of the cord also are chiefly composed of the axons of these cells. In addition to these, the following structures have been described:

I. Small medullated fibers, the axons of cells in the lateral horns of the cord, may pass out by way of the posterior roots, through the spinal ganglia, to enter the sympathetic ganglia. These are thus of the same class as similar fibers leaving the cord by its anterior roots.

II. Non-medullated fibers from the sympathetic ganglia pass through the spinal ganglia to enter the spinal canal, and to be distributed to the vessels of the cord and meninges.

III. Non-medullated fibers from the sympathetic system enter the spinal ganglia, to be distributed to its vessels.

IV. Fibers have been described, upon rather doubtful evidence, which are from the sympathetic ganglia, which enter the spinal ganglia and enter into the formation of the pericellular baskets as in the case of the axons of the cells described in the second class. This relationship is not well studied as yet.

Destination of the Posterior Root Fibers

The axons of the sensory neurons of the first order enter the cord as its posterior roots. (Fig. 31.) These fibers, upon entering the cord, divide into branches, one of which is short,

and passes downward in the comma tract for the distance of one or two segments, while the other, which is longer, passes upward in the cord by way of the fasciculus gracilis (tract of Goll) to the nucleus gracilis, or by the fasciculus cuneatus (tract of Burdach) to the nucleus cuneatus. From both the ascending and the descending branches of the entering fibers collaterals are given off to the gray matter of the segment of the entering root, and to the segments immediately adjacent, both above and below. The destination of these collaterals is as follows:

I. Collaterals form synapses with the cells of the anterior horns. In this way simple skeletal reflexes are governed.

II. Collaterals form synapses with the cells in the posterior horns. In this way the more complex reflexes are governed, and certain classes of sensations are transmitted cephalad.

III. Collaterals form synapses with the cells in the lateral horns. In this way the visceral reflexes are governed.

IV. Collaterals form synapses with the cells in Clarke's column. In this way impulses are transmitted to the cerebellum, the delicate coördinations are secured, and the impulses of the pain and temperature are transmitted cephalad.

The termination of the descending fiber is not known, but it is almost certain that it enters the gray matter, as do its collaterals.

The ascending branches terminate, for the most part, in the nucleus gracilis and the nucleus cuneatus in the lower part of the medulla. A few enter the cerebellum by its inferior peduncles.

Sensory Neurons of Higher Orders

The sensory neurons of the first order alone are immediately affected by changes in the environment or the con-

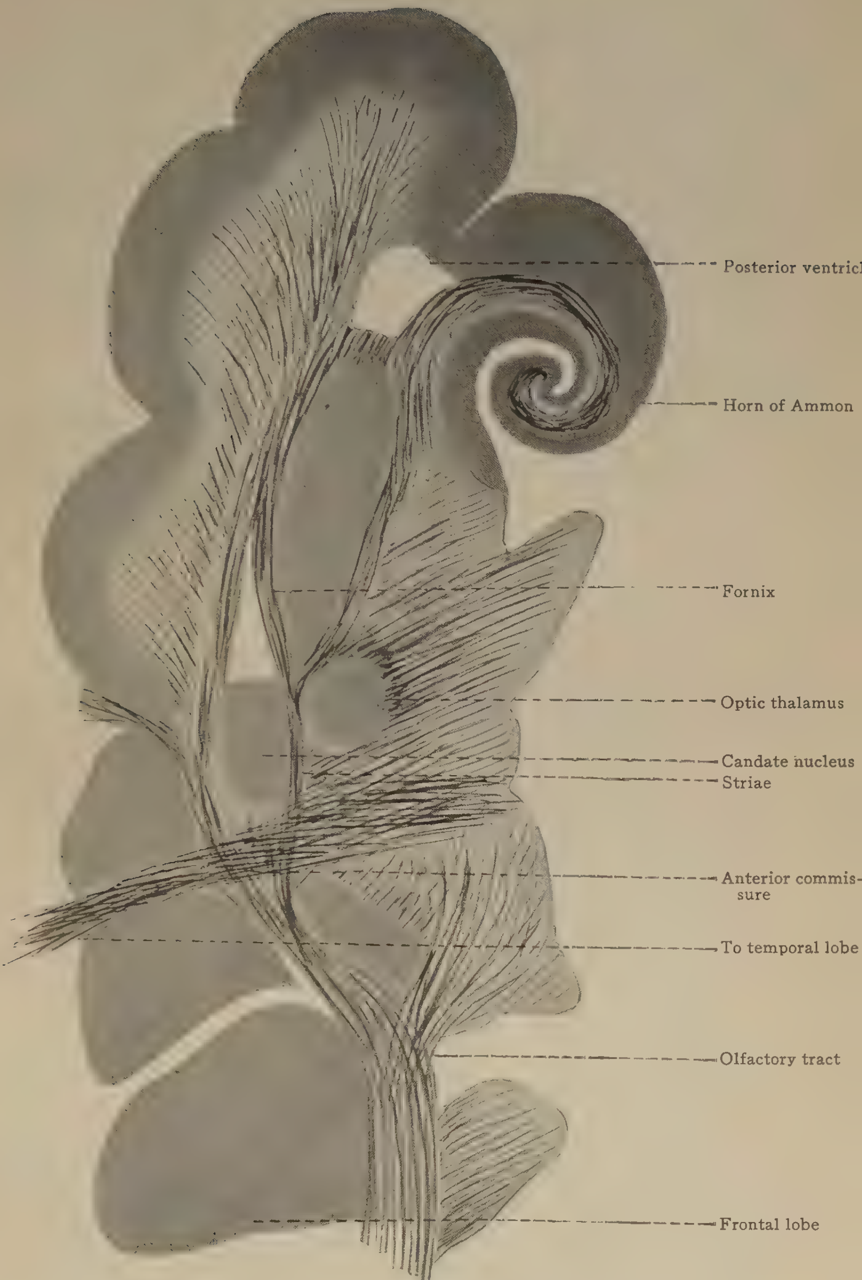


Fig. 32. Section through rhinencephalon of kitten. Cut freehand, with brain distorted so as to secure section of structures in horizontal plane. 5 diameters.

dition of the body. Sensory neurons of the second order receive nerve impulses from the neurons of the first order, and transmit these impulses either to sensory neurons of the third and higher orders, or to associational or motor neurons.

The termination of the fasciculus gracilis and fasciculus cuneatus in the nucleus gracilis and nucleus cuneatus in the lower part of the medulla has been mentioned.

The axons of the cells in these nuclei carry the impulses cephalad by two paths. The larger number of these axons pass around the olive to enter the medial fillet, and thus pass upward through the formatio reticularis of the medulla and pons, into the tegmentum, and to the optic thalamus. They enter the thalamus and form synapses with the cells of the lateral nucleus of the thalamus. Just how many cells are intervened here is not known, but some of the cells of the thalamus send axons to the post-central convolution of the brain, where consciousness is affected.

A smaller number of the cells of the nucleus gracilis and nucleus cuneatus send axons into the cortex of the superior vermis of the cerebellum. The axons, probably of the Purkinje cells, transmit the impulses to the cells of the nucleus dentatus, from which they are again transmitted to the red nucleus, and from the red nucleus to the thalamus. From the thalamus the path is as before.

Of the two ascending cerebellar tracts very little is known. It is true that the impulses concerned in the sense of muscular effort, perhaps including the impulses from the viscera, are carried to the cerebellum by way of the dorsal nucleus (Clarke's column) and the posterior ascending cerebellar tract (direct cerebellar tract, tract of Flechzig), of the same side, and in part by the anterior ascending cerebellar tract (tract of Gowers) of the opposite side. The muscular tone and the coördination of the muscular movements are probably governed in part through these impulses. From the

cerebellum sensory impulses, probably of a very dull and indefinite nature, may be carried to the cerebral cortex and affect consciousness. The path of the impulses follows that already described.

The impulses aroused by painful and thermic stimuli are probably carried by a devious way of the dorsal nucleus (Clarke's column), the anterior ascending cerebellar tract (Gower's) to the cortex of the superior vermis of the cerebellum and to the thalamus. The spino-thalamic tract diverges from the anterior cerebellar in the pons. From both these terminations the impulses are carried to the cortex by the paths already described.

The axons of the terminal nuclei of the nerves of common sensation and taste in the medulla enter the opposite medial fillet, and are carried to the thalamus, and thence to the cortex. Other fibers from these terminal nuclei enter the cerebellum and form synapses with the cells, chiefly of the superior vermis. The axons of these cells transmit the impulses to the nucleus dentatus and by these cells again to the red nucleus, the thalamus and the cortex.

Short paths may carry impulses upward and downward from one cell to another through the spinal cord, medulla, pons and midbrain. In cases of destructive lesions of certain fiber paths, it has been possible to secure a certain amount of sensation by education. In these cases the impulses travel extremely slow, and it seems probable that the short fiber paths, remnants of the primeval paths, have again assumed the duties which the higher development of the longer tracts had taken from them.

Cranial Sensory Neurons of the First Order

The cranial nerves of common sensation are homologous with the spinal sensory nerves. Their ganglia are not to be distinguished from spinal ganglia by microscopic examination.

The division of the processes within the ganglion, the amacrine and other cells of unknown function, the connective tissue network, all are present in the same relationship, so far as our present knowledge goes. The central prolongation or axon enters the medulla, divides into two branches, one of which passes downward, while the other passes upward, as do the spinal sensory roots. Both branches form synapses with the cells of the terminal nuclei of that particular nerve, and probably also of other nuclei of related function.

The vagus has two ganglia, the jugular and the nodular (ganglion of the root and ganglion of the trunk of the vagus). The peripheral prolongations are distributed very widely, to the viscera of the throat, thorax and abdomen, to the ear, meninges, etc. The axons enter the posterior lateral sulcus of the medulla and form synapses with the cells of the ala cinerae, and probably also of the solitary nucleus.

The glosso-pharyngeal nerve is concerned in the sense of taste. Though a nerve of special sense, it has the structure of the nerves of common sensation. It has two ganglia, the superior and the petrosal, both placed at the jugular foramen. The axons enter the posterior lateral sulcus of the medulla and enter into synaptic relations with the cells of the solitary nucleus and the alae cinerae.

The sensory root of the seventh, the intermediate, is also concerned in taste. Its axons enter the groove between the medulla and pons, and form synapses with the cells of the solitary nucleus and probably certain other centers.

The trigeminal has a single ganglion, very large and distinctly tripartite. It is called semilunar, and lies near the apex of the petrous portion of the temporal bone. (It was formerly called the Gasserion ganglion.) It receives sensory impulses from the face, mouth, throat, nose, eye, ear, the anterior part of the scalp, and the meninges. Its axons enter the anterior face of the pons, and form synapses with a very long nucleus,

reaching from the middle part of the pons, or higher, to the second cervical segment or lower.

With the exception of taste, the neurons concerned in the special sensations enjoy certain marked peculiarities of structure.

Higher Neurons of Cranial Sensory Conduction

The nuclei of termination of the cranial nerves of general sensation and taste have the following relations:

I. Axons of sensory neurons of the second order from these centers cross in the median raphe, enter the median fillet of the opposite side, and pass upward with that tract. Fibers are given off by this tract to both quadrigeminate bodies, to the red nucleus, substantia nigra, and to the nuclei of the reticular formation. The tract terminates in the lateral nucleus of the thalamus. From the thalamus the axons of the thalamic cells carry the impulses to the cerebral cortex.

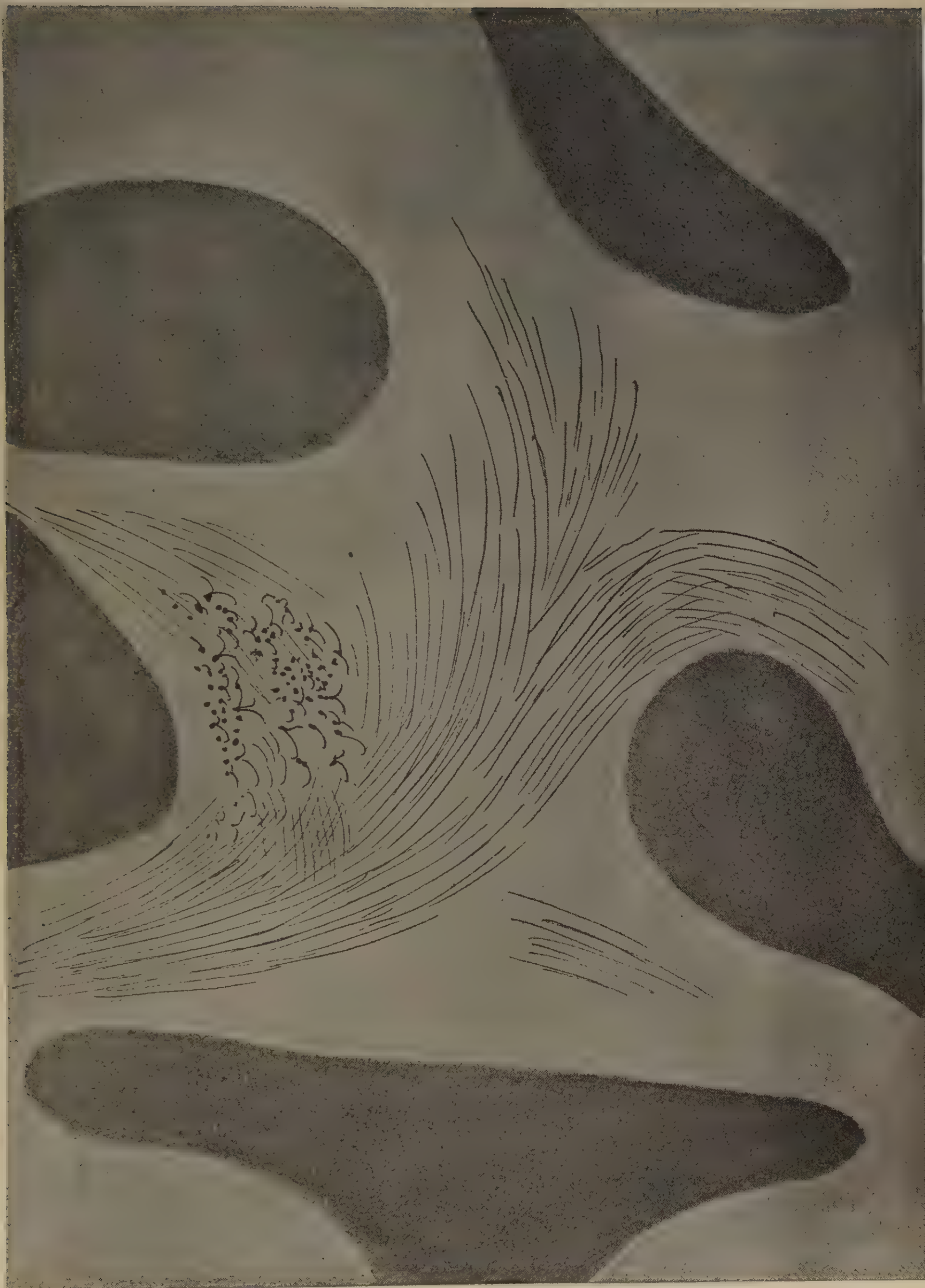
II. Axons enter the cerebellum chiefly by way of the restiform body. The impulses thus carried are concerned in coördination of the body movements, maintenance of muscular tone, etc.

III. Axons pass to the various centers of the medulla. The impulses carried by these paths are concerned in modifying the activities of these centers in accordance with cranial sensory impulses.

Auditory Neurons of the First Order

The acustic (auditory) nerve is made up of two parts, physiologically distinct, the cochlear and the vestibular.

The ganglion of the cochlear portion of the nerve is the ganglion spirale. (Fig. 33.) It is placed in the modiolus, and follows the turns of the cochlea, whence its name. The dendrites of the cells pass to the organ of Corti and thus are affected by the sound waves. The axons of the cells enter the



groove between the pons and medulla, plunge through the gray and white matter, and form synapses with the ventral and lateral auditory nuclei. Each fiber bifurcates near its nucleus, the two branches give off numerous collaterals, which form synapses with cells of the auditory nuclei.

Higher Auditory Neurons

The axons of the cells of the ganglion spirale form synapses with the cells of two nuclei, the lateral auditory nucleus, placed on the outer aspect of the restiform body, and the ventral nucleus, placed in the medulla between the restiform body and the inferior olivary nucleus. A few fibers from both nuclei join the restiform body and enter the cerebellum.

The axons of the lateral nucleus form most of the medullary striae. These fibers cross in the floor of the fourth ventricle, decussate, and plunge into the substance of the medulla to enter into the formation of the trapezoid body and the lateral fillet. A few of the fibers from the lateral nucleus pass with the fibers of the ventral nucleus.

The axons of the ventral nucleus pass ventrally and turn toward the median raphe, where they decussate. Continuing toward the opposite side of the medulla they complete the formation called the trapezoid body. Among the fibers of the trapezoid body lie many small multipolar cells, with which the auditory fibers form synapses. The axons of these cells pass onward with the trapezoid body. The fibers turn abruptly forward on the side opposite their nuclei and form the lateral fillet. The bending of these fibers occurs at about the level of the superior olivary body. Many of the fibers terminate in the superior olive and in its accessory nuclei. The axons of the cells of these nuclei join the lateral fillet.

The lateral fillet divides into two main bundles. Of these one enters the posterior quadrigeminate body of the same side. By this connection the reflexes governing the ear muscles are

coördinated. The other bundle passes anteriorly by way of the inferior brachium to the medial geniculate body. From the medial geniculate body the axons arise, which enter the acustic radiations and carry the impulses concerned in the sense of hearing to the cortex of the first and second convolutions of the temporal lobe.

A few fibers of the lateral fillet, either axons or their collaterals, enter the superior quadrigeminates. In this way the reflexes of the eye muscles following auditory stimuli seem to be coördinated.

A few fibers enter the thalamus, and the impulses are then transmitted to the cortex with the acustic radiations. Other fibers seem to terminate in the nuclei of the reticular formation, and perhaps in the motor nuclei of the cranial nerves.

Vestibular Neurons of the First Order

The short peripheral fibers, or dendrites, of the vestibular ganglion (Scarpa's ganglion) terminate among the hair cells of the cristæ and the maculæ. The axons enter the groove between the pons and medulla, and form synapses with the cells of the principal nucleus of the vestibular nerve (Dieter's nucleus) and the nucleus of the descending root of the vestibular nerve. Each fiber bifurcates near its nucleus into an ascending and a descending branch. Each of these branches gives off numerous collaterals, which are distributed in the same manner as the terminals of the fibers. Some of the vestibular axons seem to enter the restiform body, and to be distributed with those fibers to the cortex of the superior vermis.

The vestibular nerve is of interest in its phylogenetic development. Among the lower vertebrates the impulses from the middle ear and from the lateral line organs are of the most marked importance in adapting the movements of the fish to external environmental conditions. Among the animals of the upper vertebrate classes the lateral line organs disappear, the

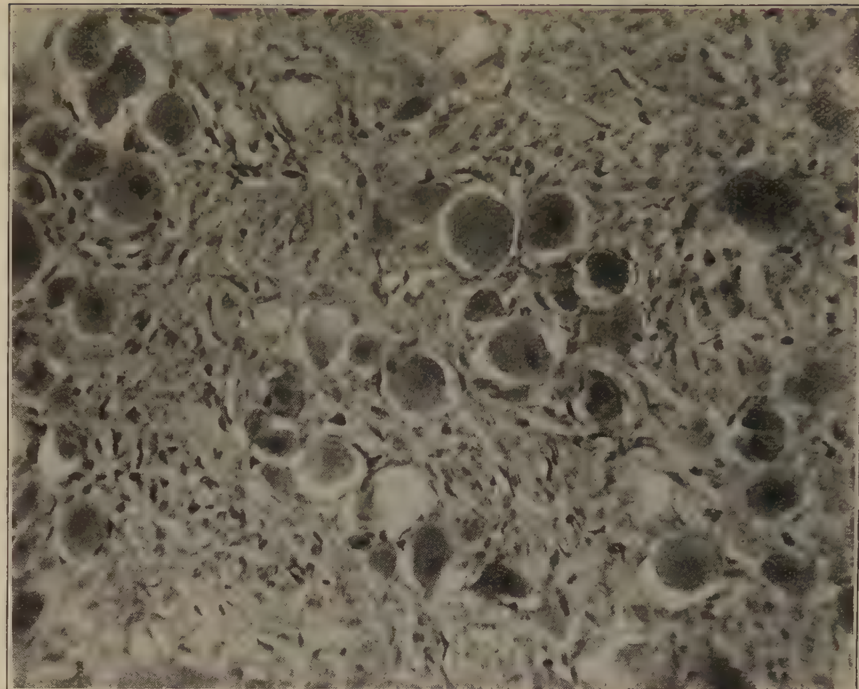


Fig. 26. Sensory ganglion, dog 1 day old. Cells show some eccentric nuclei. 200 diameters.

vestibular neurons are superseded in function in part by other more highly specialized neuron groups, and the vestibular nuclei, while retaining traces of their pristine relationships, have become almost reminiscent in function.

Higher Vestibular Neurons

The chief vestibular nucleus lies beneath the medullary striae. Lateral to this lie the nucleus of Dieters and the nucleus of the descending root of the vestibular nerve.

The nucleus of the descending root sends axons to the chief and to the accessory nuclei.

Dieter's nucleus receives fibers descending from the cerebellum, as well as the entering fibers of the vestibular nerve.

The vestibular nuclei send axons as follows:

I. Many fibers enter the cerebellum. Since the cerebellum is the most important center for the maintenance of equilibrium and for the coördination of the muscular movements, the impulses from the vestibule are of tremendous importance to that organ. Also, since the vestibular structures represent the lateral line sense organs, which originally were received by the cerebellar nuclei, the maintenance of the central relationships is very logical.

II. Fibers decussate and enter the median fillet. With this tract they pass anteriorly, giving some fibers to both quadrigeminates, and to the nucleus of origin of the abducens nerve particularly, and to the nuclei of the reticular formation. They terminate in the lateral nucleus of the thalamus. The cortical connections are not well known. Probably the temporal lobe receives the impulses from the thalamus by way of the acustic radiations.

III. Fibers from the vestibular nuclei enter the nuclei of the motor cranial nerves. Various reflex movements of the cranial muscles are thus made possible.

IV. Descending fibers terminate in the nuclei of the

sensory cranial nerves, and in the nucleus gracilis and the nucleus cuneatus.

V. Fibers pass to the inferior olivary nucleus; the function of this relationship is not known. It is probably concerned in muscular coördination and equilibrium.

VI. Fibers pass downward through the cord as the vestibulo-spinal tract. This tract, of great value in fishes, is probably of very less importance in mammals. It carries impulses which are concerned in the maintenance of muscular tone, equilibrium, and perhaps in certain coördinations. Its injury is not productive of any but the most transient symptoms.

Visual Neurons of the First Order

The visual apparatus presents a number of variations from the typical sensory mechanism.

In the first place, the retina is embryologically derived from a portion of the brain vesicles. It is not formed, as are the spinal ganglia, by wandering cells from the neural tube, but it is an outgrowth of the brain itself. Later, the part connecting the retina and the rest of the cerebral masses becomes atrophied. The axons of the ganglion cells of the retina follow the pathway of the obliterated nerve matter to the brain. The fibers of the optic nerves are, then, to be considered as homologous with the brain tracts, rather than with the roots of the spinal cord.

In the retina several different types of neurons are found. The light first affects the layer of rods and cones, these transmit the stimulation to the layer of bipolar cells, these in turn affect the ganglionic cells, and it is the axons of these cells which transmit the nerve impulses toward the brain by way of the optic nerves and tracts. Among these nerve cells of the retina are found also certain others — the so-called horizontal cells, whose axons pass horizontally and terminate

among the bipolar and ganglionic cells, after the manner of the Dogiel cells in the sensory ganglia. Amacrine cells are found, whose dendrites branch freely among the other cell elements of the retina. There is some reason for supposing that the efferent fibers of the optic nerve terminate in the midst of the amacrine cells. If this be true, then the efferent impulses which, apparently, govern the nutrition of the retina, are effectual through the amacrine cells.

There is room for doubt concerning the place of the visual sensory neurons of the first order. There is no doubt that the rods and cones are first affected by light, but the question arises concerning the nature of these structures. Their structure resembles greatly some of the specialized sensory nerve endings, and they are so considered by Barker and by certain other neurologists. The bipolar cells are thus to be considered as the sensory neurons of the first order. This view makes the bipolar cells homologous with the spinal sensory neurons, and the presence of the horizontal and amacrine cells in this layer of the retina adds favor to the view. The crux of the matter depends upon the real nature of the rods and cones — if these be neurons, then the bipolar cells are sensory neurons of the second order. If the rods and cones are specialized sensory nerve endings, then the bipolar cells are of the first order, as Barker supposes. The matter is of importance only from the academic standpoint, and in considering the pathology of certain diseases of the nervous system.

The ganglionic cells are homologous with cells of the nuclei of termination of the cranial sensory nerves. The optic nerves and tracts are homologous with fibers of the fillet. The fibers of the optic nerves and tracts are imbedded in neuroglia, as are the tracts of the central nervous system, and as true nerves are not. The embryonic development of the tracts follow the course of the development of the cerebral tracts.

Higher Visual Neurons

Just at the olivary body in front of the sella turcica the two optic nerves approach, and partially decussate. The fibers from the nasal halves of both retinæ cross, while the fibers from the temporal halves of both retinæ remain on the same side. The fibers emerging from the optic chiasm are called the optic tracts. The left optic tract thus contains the axons of the ganglionic cells of the left halves of both retinæ, the right optic tract contains the axons of the ganglionic cells of the right halves of both retinæ. The macula lutea is about equally represented by both crossed and uncrossed fibers.

Of the optic tracts, about one-fifth of the fibers enter the superior colliculus and form synapses with the cells of its deeper layers. Here are coördinated the impulses concerned in the movements of the intrinsic and extrinsic eye muscles.

The larger division of the optic tracts, comprising about four-fifths of the fibers, enters the lateral geniculate body and the pulvinar of the thalamus. It is not possible to determine how many cells are interposed in the pathway of the visual impulses through the thalamus, but certain of the axons finally pass to the cortex of the pole of the occipital lobe, where consciousness is affected.

Olfactory Neurons of the First Order

The bodies of the olfactory sensory cells lie in the mucous membrane of the nose. The region is called the regio olfactoria. It is very small, covering only about two hundred and fifty square millimeters on each side. These cells send dendrites toward the surface, where each fiber branches into very fine fibrillæ, which are supported by modified epithelial cells called "sustentacular." These fine branching fibrillæ are capable of being stimulated by substances in gaseous form, or possibly also by substances in solution. The axons of the

Fig. 34. Olfactory lobe of kitten, 6 days old. Semidiagrammatic. 60 diameters.

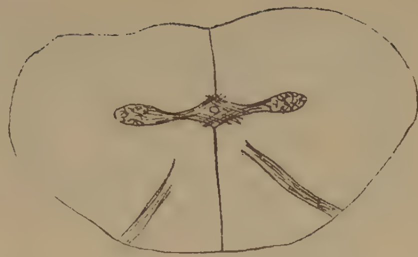


Fig. 35. Spinal cord of shark. 10 diameters.

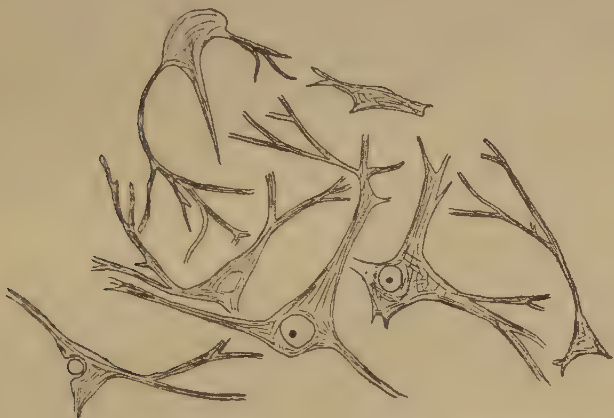


Fig. 36. Cells from gray matter of figure 35. 250 diameters.

Fig. 37. Section through cervical enlargement of adult dog. Semidiagrammatic Anterior aspect is upward. The posterior root fibers enter the cord and form synapses with cells in anterior horn.

olfactory cells pass upward in twenty or thirty bundles through the cribriform plate of the ethmoid bone, and enter the olfactory lobes. These axons make up the olfactory nerves. In the olfactory lobe the axons pass around the periphery for a variable distance, then penetrate the lobe. Here they break up into fine branches and twist around into a globular form, making the olfactory glomerulus. Into the glomerulus also enter the dendrites from the mitral cells, in a deeper layer of the olfactory lobe. The axons of the mitral cells pass brainward as the olfactory tracts. (Fig. 34.)

The olfactory nerves are not medullated, as are all other cerebro-spinal nerves in the adult. The cell bodies lie in the mucous membrane. This arrangement differs from all other nerve cells of the body of vertebrates. Only in invertebrates are nerve cells to be found peripherally placed, with this exception.

Higher Olfactory Neurons

The axons of the olfactory neurons of the first order form synapses with the olfactory neurons of the second order by means of the glomeruli of the olfactory bulbs. The olfactory neurons of the second order, the mitral cells, and possibly also the granular cells of the olfactory bulbs, send axons brainward by way of the olfactory tracts. (Fig. 32.)

The olfactory tracts carry fibers passing in both directions. Efferent fibers from the olfactory centers enter the olfactory lobes, and form synapses with the cells therein, apparently in all layers of true nerve cells. Efferent fibers seem to descend through the cribriform plate to the olfactory region of the nasal mucous membrane, though this matter requires further study.

The olfactory tracts are composed of three roots. These, as they diverge, inclose the olfactory trigonum, an area of gray matter which is continuous with the anterior perforated

space, the parolfactory area, the tuberculum cinereum, and neighboring gray matter. The three roots are called lateral, medial and dorsal or middle.

The lateral root passes directly to the amygdaloid nucleus, the hippocampus major, and neighboring areas. In passing, collaterals and terminals are given off to the gray matter of the inferior parts of the temporal lobe. Just how great an area of the inferior aspect of the brain and of the temporal lobe is included in the distribution of the lateral olfactory root is not yet known. It seems very probable, in the microsmatic human being, that many of the connections thus secured are reminescent rather than actually functional. It is certainly true, however, that the function of the olfactory impulses in the unconscious coördinations is not to be measured exactly by any conscious factors, nor, indeed, in any exact manner by the phenomena of apparent reactions.

The median root of the olfactory tract enters the anterior commissure. This requires a short discussion.

The Anterior Commissure

This is a bundle of fibers which unite the lateral portions of the rhinencephalon. It is to be considered in two parts. The anterior part is composed of a bundle of fibers from the median olfactory root, which pass directly to the opposite side of the brain, and pass backward in the fornix, the stria medullaris and the septum pellucidum to be distributed, after losing some fibers in the gray matter traversed or passed, in the hippocampus major and the amygdaloid nucleus.

The posterior bundle of the anterior commissure is composed of fibers which gather together from almost or quite all of the temporal lobes, decussate, and pass to the head of the caudate nucleus, to the areas of the temporal lobes, to the olfactory trigonum and the neighboring gray matter, and the olfactory bulbs, all of the opposite side. The anterior com-

missure pierces, or is pierced by, the stria medullaris and the external capsule fibers as they pass forward and medialward.

It thus appears that the lateral roots are concerned in a rather scanty sort of crossing for the olfactory impulses. It is very evident that the olfactory impulses are largely carried by uncrossed tracts. The two sides of the rhinencephalon are intimately related by the various commissures.

The dorsal or middle root of the olfactory tract plunges upward into the gray matter of the trigonum and neighboring gray matter. Part of the fibers form synapses with the cells in this area, but the larger number enter the fornix and the striæ medullaris and pass to the hippocampus of the same side of the brain. Thus the fornix receives fibers of olfactory function at both its extremities, and the hippocampal region both receives and sends fibers by way of the fornix and striæ.

The hippocampal region of each side is related to its fellow of the opposite side by way of the horizontal fibers of the psalterium or lyre. This peculiar structure is concerned in carrying the olfactory impulses also. It is composed of the ascending and converging bundles of fornix fibers, between which pass small bundles of commissural fibers. These fibers carry impulses from each temporal lobe, and especially from each hippocampus, to the homologous contralateral areas.

The further connections of the olfactory region are complex.

The amygdaloid nucleus and the hippocampus, chiefly the uncus and dentate fascia, send axons by way of the fornix to the corpora mammillaria, partly of the opposite side, but chiefly of the same side. The fornix fibers terminate by forming synapses with the cells of the lateral or the median nucleus of the mammillary bodies. The axons of cells of the median nucleus of the mammillary bodies pass upward and bifurcate. The bundle which is composed of one set of these branches

Fig. 38. Cross section through cord of human embryo of about 10 weeks. Central canal is lined with ciliated epithelium. Nerve cells are small, round, closely packed, with nuclei occupying almost the entire cell.

is the thalamo-mammillary bundle (bundle of Vicq d'Azyr). It enters the anterior tubercle of the thalamus.

The second branch of the fibers from the median nucleus passes into the tegmentum and downward into the reticular formation. It seems to terminate in the neighborhood of the lateral nuclei of the reticular formation, probably in the superior and the central lateral nuclei. Collaterals and probably terminals are given off in passing to the red nucleus, substantia nigra, and hypothalamic nuclei.

The axons of the cells of the smaller lateral nucleus of the mammillary body pass downward through the midbrain, and seem to end in the gray matter around the cerebral aqueduct. Fibers are given also to the red nucleus and neighboring centers. Through the mammillary bodies, the olfactory impulses are thus distributed to the centers which are concerned in the viscero-motor and the emotional and instinctive reactions.

The Nucleus Habenulae

The nucleus habenulae also is concerned in the olfactory coördinations. This nucleus receives the axons of the cells of the hippocampal region by way of the thalamic striæ. These fibers enter the nucleus habenulae, both of the same and of the opposite sides, and form synapses with the cells therein. From the nucleus habenulae the fibers pass, as the fasciculus retroflexus (of Meynert), to the nucleus of the interpeduncular region, and the cells of this ganglion transmit the impulses thus carried to the nuclei of the motor cranial nerves. In this way the somato-motor effects of the olfactory impulses are carried — that is to say, the olfacto-somatic reflexes are coördinated.

CHAPTER VII

THE CONTROL OF THE MOTOR NEURONS

The motor neurons of the first order are those whose axons are distributed to the active structures of the body. The term is not usually applied to the sympathetic neurons, though these cells are as truly motor neurons of the first order as are the cerebro-spinal neurons. The lack of exact information in regard to the relationships within the sympathetic ganglia renders the use of these exact terms inadvisable at the present time. So the term "motor neuron of the first order" is usually applied only to the cerebro-spinal neurons whose axons are distributed to the skeletal muscles. Motor neurons of the second order are those neurons whose axons form synapses with the motor neurons of the first order, and which transmit the impulses from the higher centers. The sensory neuron of the first order might send its axon or collateral to the motor cell; but since it does not transmit impulses from the higher centers, it could not properly be called "motor" neuron at all. Thus it appears that the distinction between the sensory and the motor neurons is not always easy to make. Both the sensory neurons of the first order and the motor neurons of the first order are distinguishable by their peculiarities of structure and of relationships, but the neurons of higher orders are not easily classified in all cases. The motor neurons of the first order are controlled by the impulses reaching them from other parts of the

nervous system. Except for the direct effect of the constituents of the blood and lymph upon the neurons, the ultimate control of the motor neurons is from the streams of sensory impulses.

The Somatic Motor Neurons

The somatic motor neurons of the first order occupy a column placed in the anterior horn of the spinal cord and extending into the medulla, pons and midbrain. The part of this column which lies within the cord is fairly regular in outline and in the number and position and appearance of the cells. In the medulla the column is crowded toward the median line by the spreading of the posterior fissure as it widens out into the fourth ventricle and the consequent displacing of the lateral and posterior funiculi. The interposition of the masses of gray matter of the medullary nuclei, the decussation of the pyramids and of the fillet, and the passing of the tracts associated with the cerebellar peduncles, all help to distort the column of the somatic motor neurons in the medulla and pons so greatly that only the study of the phylogenetic and ontogenetic development of the neuron groups makes their homology with the spinal somatic motor neurons recognizable.

The motor neurons of the first order are of large size and of rugged outline. They are very closely crowded during embryonic life. During later development they are crowded apart by the increasing development and growth of their own dendrites and by the richly interlacing pericellular baskets which grow around them. Their axons are distributed to the skeletal muscles. Those of the spinal cord pass outward by way of the anterior roots. The axons, in the adult neuron, become medullated within a few microns of the exit from the cell body, and this medullary sheath is retained throughout the whole length of the axon, except where it is interrupted

by the nodes of Ranvier, and within a few microns of the termination of the fiber in the motor nerve ending upon the muscle fiber. The axons of the cranial motor neurons of the first order are arranged in a similar manner, but display a few variations, due to the requirements of the peculiarities of the cranial structures and their development.

The pericellular network is very close and complex. It is composed in part of the dendrites and fibrillæ of the motor neurons themselves, and in part of the branching axons and collaterals from other neurons. Sometimes a collateral from the axon of the motor cell itself enters into this basket. It does not seem that there is any protoplasmic continuity of the fibrils, though this matter is at present a matter of doubt. It is certain that the network is extremely dense, and that the transmission of the impulses carried by the axons and collaterals have every opportunity to affect the dendrites and fibrillæ of the motor neurons.

The motor neurons of the first order receive impulses from the following sources:

I. Axons and collaterals from the sensory neurons of the first order form synapses with the motor neurons of the first order. By this means the simplest possible reflex actions are made possible.

II. Axons and collaterals from the sensory neurons of the second order, notably those of the posterior horns of the spinal cord and of homologous cell groups in the higher centers, form synapses with the motor neurons of the first order. By this means reflex movements requiring the coördinated action of simple muscle groups are secured. (Fig. 44.)

III. Axons and collaterals from adjacent segments of the cord, and from adjacent centers in the higher motor cell groups, affect motor neurons of the first order. By this means the more complex reflex actions are controlled.

IV. Descending fibers carry impulses from the cerebel-

lum. These may be axons directly from the cerebellar cells, or they may be axons from the cells of the central cerebellar nuclei, the olive, and perhaps of other similar cell groups very closely connected with the cerebellar centers. By this means the most complex of reflex actions, such as those concerned in walking and standing, may be secured.

V. Descending fibers from the red nucleus and certain other cell groups included as basal ganglia make up the rubro-spinal tract. The impulses carried by these fibers stimulate the motor neurons in such a way as to cause the instinctive and emotional reactions.

VI. Descending fibers from the vestibular nuclei, passing in the vestibulo-spinal tract, carry to the motor neurons certain impulses originating in the semi-circular canals. These impulses, of much less importance in mammals than in fishes and amphibia, are probably concerned in the maintenance of the symmetrical and the erect position.

VII. Descending fibers from the quadrigeminate bodies are carried by the tecto-spinal tract (anterior longitudinal bundle). These, like the vestibulo-spinal fibers, are representative of an ancient arrangement for the coördination of the impulses in the complex actions necessary to the maintenance of life. Impulses chiefly from the retina and cochlea initiate descending impulses over this tract to the motor neurons of the first order. It is probable that in this way the tone of the skeletal muscles is partly affected, and that a certain amount of complex coördination is secured, especially in reactions following visual stimuli.

VIII. The pyramidal tracts carry impulses from the central or kinesthetic area of the brain (Rolandic area). These fibers form synapses directly with the nerve cells of posterior or base of the anterior horn, and the axons of these in turn enter into the pericellular basket of the motor neurons of the first order. The impulses carried by this tract are con-

cerned in the control of the movements called volitional, and which are also usually well recognized in consciousness.

IX. Descending fibers from certain autonomic centers in the medulla, midbrain and the pons carry impulses concerned in the performance of the autonomic functions to those skeletal muscles needful for those duties. This is exemplified in the action of the respiratory center in the lower part of the calamus scriptorius. Impulses from the respiratory centers are carried downward in the cord, probably through the fasciculus proprius, to the motor cells controlling the different respiratory muscles. The vomiting center, the deglutition center, and other of similar action, all act through descending impulses to the skeletal muscles concerned.

By means of these varying methods of control of the motor neurons of the first order, with their varying degrees of structural complexity and the related variations in the complexity and numbers of the sources of sensory impulses from which the different stimulations are derived, the motor impulses are made of such quality that comparatively simple muscular mechanisms are enabled to serve remarkably complex purposes. The simple reflexes serve the purposes of simple needs. They are not especially coördinated, serving the immediate needs of the organism quickly. The more complex reflexes serve the needs of the body for the complex actions, expressive of the needs of the many individuals of the race, alike for all individuals, the result of racial experiences, of many survivals and of infinite deaths.

The more delicately coördinated reactions, especially those depending upon the cerebellum and its related ganglia for their control, are of even greater complexity, and are the results of the experience of the individual, chiefly and perhaps exclusively. These reactions are initiated and modified and controlled, largely, through educational methods. The volitional impulses, again, while probably controlled by sim-

pler structures than those coördinated by the cerebellum and the related centers, are of a more complex nature in that they are the result of present sensory impulses, modified by the results of the history of each individual, plus the past of his neighbors with whose experiences the individual is familiar, plus the results of the stimulation of the association cells, whereby the action and its results are foreseen, even though it may be, as a whole, totally apart from the experience either of the individual or his race. This complexity of coördination is possible only because the cells of the central convolutions, as well as of other parts of the cerebral cortex, are affected by inhibiting impulses.

Control of the Viscero-motor Neurons

The visceral muscles are innervated through the sympathetic nervous system, as it is illogically termed. This part of the nervous system includes a number of ganglia placed in various parts of the body cavities, and the fibers which relate them to the spinal cord, pons, medulla and midbrain.

The nerve cells in the sympathetic ganglia are controlled by the impulses from the cells in the lateral horns of the cord (the lateral group of the anterior horns, according to certain writers) and in homologous centers in the medulla, pons and midbrain. These autonomic centers are themselves controlled by the impulses from higher centers and from the sensory neurons. The sympathetic ganglia do not, under any but experimental conditions, act independently.

The nerve fibers which transmit impulses from the autonomic centers in the central system are of finer caliber than are the fibers from the somato-motor neurons. The autonomic fibers make up most of the bands called the white rami communicantes, which leave the spinal cord in the dorsal region — that is, from the first or second thoracic segment to the second or third, or sometimes the fourth, lumbar seg-

ments. These white rami enter the sympathetic ganglion nearest their origin, usually, but rarely terminate until they have passed through one or more ganglia. Then they break up into fibers which form a part of the pericellular net around the bodies of the nerve cells of the sympathetic ganglia. Each axon of the white rami may send collaterals to several different sympathetic cells in a single ganglion, and it seems probable that collaterals from the white rami fibers may pass from one ganglion to another, thus bringing the cells of two or more ganglia under the control of a single white rami fiber. On the other hand, each sympathetic cell may receive fibers from two or more white rami fibers. Thus the activity of a single sympathetic cell may be modified by the impulses from several cells within the central nervous system, and the impulses from a single cell within the central nervous system may modify the activity of many sympathetic cells. The complexity of these structural relationships accounts for the well-known complexity of the functional relationship between the sympathetic and the central cells.

The vagus, the third cranial, the seventh and perhaps the ninth cranial nerves also send fibers, comparable in function, to the sympathetic ganglia. In the pelvis, the nervus erigens sends fibers to the hypogastric ganglion.

The autonomic cells in the lateral horns of the cord and the homologous centers in the medulla, pons and midbrain are somewhat smaller than are the cells of the somato-motor centers. They are not quite so rugged in outline; the dendrites are shorter and less profusely branching. They are surrounded by a network which is similar to that already described as surrounding the somatic motor cell bodies. This network includes the fibrillæ derived from the spongioplasm of the cell body, and also the axons and collaterals from the following cells in other parts of the nervous system:

I. Collaterals from the axons of the entering posterior

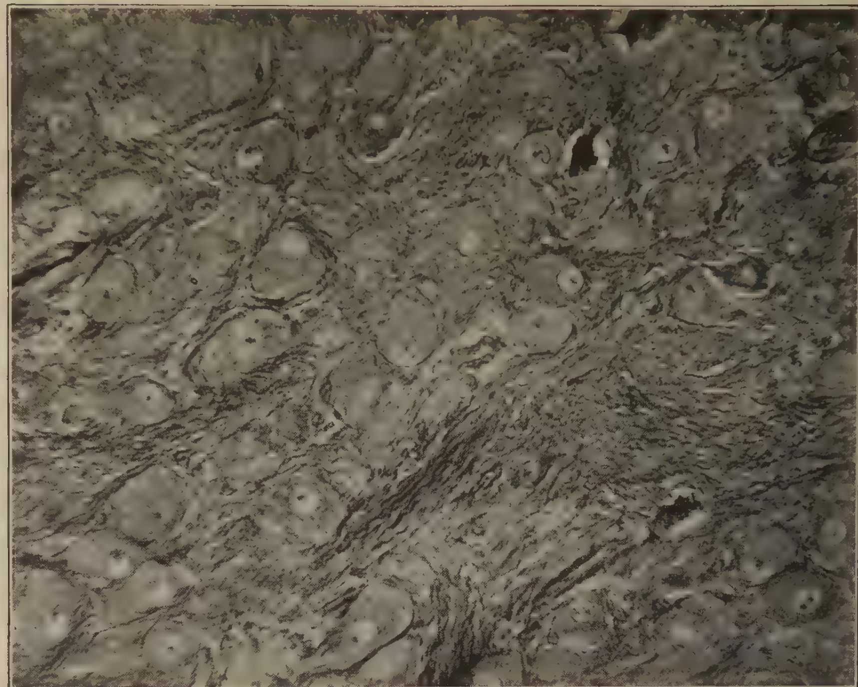


Fig. 39. Sympathetic ganglion of adult dog. The pericellular baskets are shown. About 200 diameters.

roots of the cord bring to the lateral horn cells impulses from the sensory neurons of the first order. (Fig. 45.) These include (*a*) viscero-sensory neurons, by means of which the visceral conditions initiate or modify the autonomic impulses to the sympathetic ganglia and thus to the muscles, glands and blood vessels of the viscera, (*b*) somatic sensory neurons, by means of which impulses from skin, muscles and joint surfaces may modify visceral action.

II. Axons and collaterals from the cells of the posterior horns of the cord probably have functions similar to those just mentioned.

III. Fibers from the cells of the opposite side of the cord bring the two halves of the body into functional relationship.

IV. Terminals and collaterals from the descending rubro-spinal tract bring impulses from the red nucleus, the substantia nigra, and probably others of the basal ganglia, to the autonomic cells. Thus the emotional reactions include visceral as well as somatic manifestations.

V. Descending impulses are carried from the various centers in the medulla, midbrain and pons to the viscero-motor neurons in the cord. The vaso-motor center, the heart centers, and other viscero-motor centers act in this manner.

According to their termination, the viscero-motor neurons have the following functions:

I. They contract the walls of the blood vessels, especially of the arterioles, thus decreasing the blood supply of that certain area and raising the general blood pressure in corresponding degree.

II. They cause contractions in several manners of the walls of the alimentary canal, the heart, the urinary and the gall bladders, the uterus, and other organs and ducts of the body. In this way the contents of these hollow viscera are variously propelled.

III. They contract the pupilo-dilator, the pupilo-con-

strictor, the ciliary muscles, and the other non-striated muscle fibers of the orbit.

IV. They contract the pilo-motor muscles, by means of which the hair, feathers, quills, and other varieties of the exo-skeleton are made erect during cold, fear, anger, etc. In this way the loss of heat from the body is lessened, the danger of wounds in battle is lessened, and the animal is caused to assume a more ferocious appearance.

V. They increase the secretions of glands in all parts of the body.

VI. Certain of these fibers seem to have the power of inhibiting the action of those just mentioned. The manner in which the inhibiting fibers act is one of the greatest puzzles of physiology.

It seems that the inhibitory function is exercised only by neurons of the central nervous system upon other neurons, either of the central system or of the sympathetic ganglia. The existence of inhibitor neurons of the first order is not demonstrated, and their existence is extremely improbable.

The stimulation of the sympathetic nerves to the salivary glands increases the secretion of these glands, but the secretion is very thick and rich in organic matters. The blood vessels are greatly constricted. The stimulation of the cerebrospinal nerves to the same gland, as the chorda tympani, on the other hand, also increases the secretion, but in this case the fluid formed is very thin and watery, containing a certain quantity of inorganic salts, but very little organic matter. The blood vessels are tremendously dilated. Just what the real relation is between these nerves and their action is not yet known. The circulatory changes must modify the character of the secretion also. If all nerve impulses are identical in quality, as seems indicated by many of the phenomena of nerve activity, then there must be some structural difference in the relations of the two classes of nerve with the glands they

supply. On the other hand, if nerve impulses are not identical in quality, then we have before us the more complex, but not more explicable, problem of differentiating between the almost infinite varieties of classes of impulses needed for the determination of the almost infinite variety of physiological activities controlled by the nervous system.

The viscero-motor neurons are not directly influenced by the volitional impulses from the somesthetic area. But they may be influenced indirectly in either of two ways.

If one remembers distinctly the events which are associated with emotional reactions in his own past, or if he imagine distinctly, in such a way as to present vividly before himself a series of incidents which bring to him any emotional state, the muscles concerned in such emotional state become contracted involuntarily, and the viscera whose activity is usually associated with such emotions become active. The reactions thus produced are not ordinarily so strenuous as those produced by the actual presence of the emotion-producing circumstances, but at times they seem even to be increased in memory or imagination beyond that characteristic of the actual occurrence. This is noted with disastrous circumstances in the effects of certain mental shocks. In these cases the memory of the fright is often more unendurable than the occurrence itself seemed to be. The phenomena of hysteria and of certain insanities illustrate this reaction. Probably no rational use can be made of this relationship in therapy.

The lateral and anterior horns are so closely associated in the gray matter that the stimulation of one group of cells is practically certain to affect the action of other groups of the same segments. Thus the stimulation of the skeletal muscles of any segment, by means of volitional impulses, affords a certain amount of normal stimulation to the visceral muscles and glands also. In those cases of cardiac lesions in

which hypertrophy is desired, it is very good to cause the gentle use of the arm muscles and the intercostals. In cases of visceroptosis, dilated stomach, intestinal atony, etc., much good can be accomplished by the patient himself if he will use conscientiously those exercises which increase the tone of the skeletal muscles innervated from the same spinal segment.

In any forms of exercise, if the elements of enjoyment and desire can be added to the volitional impulses, if the patient can be made to enjoy the exercises, or to feel some emulation, then his progress in strength is more rapid. For this reason useful exercises are best, other things being equal. In all these cases the additional stimulation due to the emotional state is associated with a stream of impulses from the red nucleus and related basal ganglia.

The Motor Cranial Nerves

It is not possible to divide the cranial nerves into exactly two classes, somatic and visceral, because in the case of these nerves the original distribution and function has been so greatly modified through both ontogenetic and phylogenetic development. It becomes necessary, then, to consider their relations separately, and to view them in the light of their present functions and relations, noting their ontogenetic and phylogenetic relationships only with such care as will serve to explain in part their irregularities.

The hypoglossus or twelfth cranial nerve is, in the adult, purely motor. In the embryo it has one or two sensory ganglia, with corresponding embryonic sensory roots. These become lost in development. The hypoglossus contains fibers corresponding to about five nerve segments. It arises from a genetic nucleus in the floor of the fourth ventricle, in the trigonum hypoglossi. Its nucleus is in direct line with the anterior horns of the cord, and it is a somatic motor nerve in development as in present function. The fibers pass through

and between the inferior and the accessory olives and emerge from the anterior sulcus of the medulla. It is distributed to the muscles of the tongue and the depressors of the hyoid bone.

The hypoglossal nucleus receives association fibers from the other motor cranial nerve nuclei, notably the fifth and seventh, and from the sensory cranial nerve nuclei, notably the fifth, seventh, and eighth.

Descending fibers from the pyramidal cells of the lower part of the precentral convolutions of the cerebral cortex form synapses with the cells of this nucleus, and by this pathway the volitional movements of the tongue and probably the movements of the tongue in speech are effected.

Impulses from the deglutition center in the medulla affect this nucleus.

Impulses from the red nucleus and other basal ganglia reach the hypoglossal nucleus, and it is in part because of this connection that in emotional disturbances the tongue becomes stiff — in other words, the emotional effects upon the tongue are, directly, inhibiting. It is scarcely needful to state that this inhibition is frequently less potent than the stimulation afforded by the descending impulses from the volitional centers in times of emotional stress of certain types.

The Accessory Nerve

The accessory, or spinal accessory, nerve is to be considered in two parts. The cerebral root originates in the nucleus ambiguous. It is morphologically and physiologically a part of the vagus, and the fibers derived from this nucleus join the vagus after their exit from the cranium. The fibers of the spinal root originate in a column of cells at the lateral portion of the upper five segments of the cord. These fibers pass upward in the canal, join the cerebral root, and leave the cranium by the jugular foramen. It is distributed to the trape-

zius and the sterno-mastoid muscles. One or two rudimentary sensory ganglia have been found in embryos upon the spinal accessory nerve.

The origin of this nerve from a nucleus in the column of the viscero-motor nerves appears at first sight an anomaly. In its phylogenetic development the peculiarity disappears. The trapezius and sterno-mastoid muscles are derived from the old branchial musculature, and are, therefore, phylogenetically, visceral muscles. Their innervation from the column in line with the other visceral motor nuclei is thus appropriate, though the muscles are at this time skeletal, striated, and as thoroughly under the control of the volitional impulses as any other voluntary muscles.

The spinal nucleus of the spinal accessory receives impulses from the sources already mentioned as influencing the activities of the spinal motor neurons.

The Vagus Nerve

The motor fibers of the vagus arise chiefly from the nucleus ambiguous, but some fibers arise also from the neighboring gray masses in the medulla. This nucleus belongs to the column of the viscero-motor neurons. The cells are, like those of the spinal lateral horn, rather small, multipolar cells, with rather fine axons. The vagus is, phylogenetically and physiologically, a viscero-motor nerve. Its motor fibers are homologous with the white rami fibers. They terminate by forming synapses with sympathetic cells.

The motor nucleus of the vagus receives impulses from the following sources:

I. The sensory fibers of the vagus send collaterals and probably terminals to the nucleus ambiguous.

II. Axons and collaterals from the sensory nuclei of the fifth, seventh and eighth cranial nerves, the nucleus gracilis

and nucleus cuneatus, form synapses with the cells of the nucleus ambiguous.

III. The various centers of the medulla, the cardiac, the vaso-motor, the respiratory, etc., either are identical with the nucleus ambiguous and the neighboring gray matter from which the vagus motor fibers arise, or they are very intimately related to these by association neurons and by collaterals from the afferent and efferent axons.

IV. The rubro-spinal and tecto-spinal tracts, the descending root of the fifth, the vestibular nuclei, the olives, and the pontine nuclei, send axons and collaterals to the nucleus ambiguous. By this means the various activities of the vagus are modified by sensory impulses from practically every part of the body.

Pyramidal fibers do not seem to affect the action of the vagus, and are not described as entering the nucleus ambiguous.

The Glosso-Pharyngeal Nerve

The motor fibers of the glosso-pharyngeal nerve arise chiefly from the nucleus ambiguous, and also from the nucleus of the alae cinerae and certain small cell groups in the immediate neighborhood. This is phylogenetically a viscero-motor nerve, and its nucleus is a part of the viscero-motor column. Its function is essentially visceral, since it is concerned with deglutition. The constrictors of the pharynx are remnants of the branchial musculature. The nucleus ambiguous receives associational fibers from the other cranial nerve nuclei, as has been given in the case of the vagus. The reflexes with which the glosso-pharyngeal nerve are concerned are chiefly those of deglutition.

The glosso-pharyngeal motor neurons receive fibers from the pyramidal cells of the inferior part of the precentral convolutions. By means of this relation it becomes possible for

the act of swallowing to be voluntarily performed or inhibited, to a certain extent.

Fibers carrying inhibitory impulses seem to reach the glosso-pharyngeal nuclei from certain autonomic centers in the medulla, since the act of swallowing is urgently inhibited during coughing, mastication, etc. The descending impulses from the red nucleus and related centers appear to be chiefly inhibitory, since emotional disturbances inhibit swallowing. The dryness of the mouth associated with certain emotions, however, initiates the swallowing reflex in many emotional conditions.

The fibers emerge from the upper end of the posterior sulcus of the medulla, join the sensory roots, and pass through the jugular foramen to reach their area of distribution, the pharyngeal constrictors and the stylo-pharyngeus muscle.

The Facial Nerve

The motor fibers of the facial nerve are the axons of the nerve cells of a single nucleus in the pons, under the superior fovea. This nucleus is a part of the continuation of the lateral horn of the cord, and the nerve is phylogenetically a viscero-motor nerve. Originally its motor fibers innervated the gill muscles. It is specifically the nerve of the hyoid arch, and only secondarily is it a nerve of expression. Its nucleus does not give fibers to the sixth, as is sometimes stated, but some fibers of the sixth run in the same path for a certain distance in the neighborhood of the genu of the facial.

The fibers leave the groove between the pons and medulla and pass with the sensory root of the facial to the muscles of expression — that is, to the muscles of the face, but not those of mastication.

The motor nucleus of the seventh has certain peculiarities which affect its liability to disease. In the first place, its almost constant use renders its constituent neurons irritable

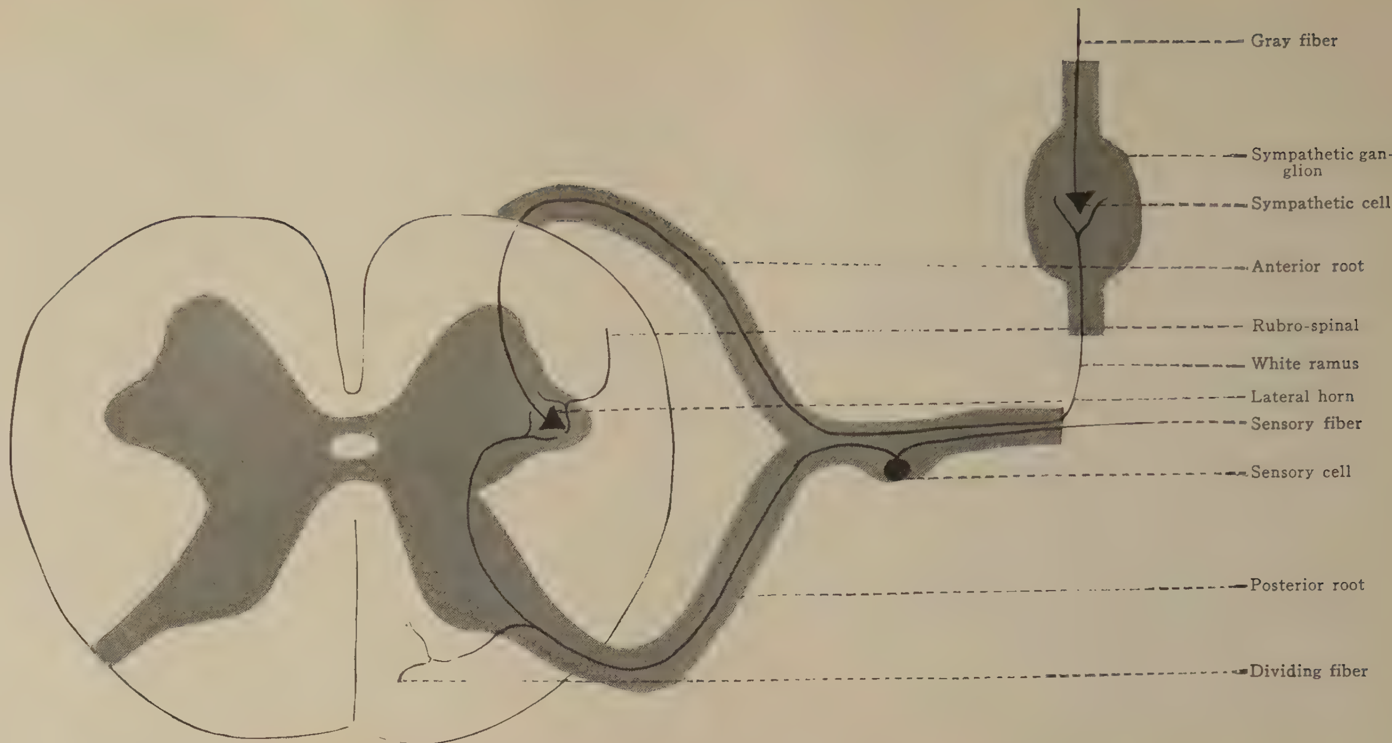


Fig. 40. Cilio-spinal center.

beyond the common habit of neurons. The liminal values thus being lower than is usual, excessive stimulation, the presence of the fatigue products in the blood stream, reflex irritations originating almost anywhere in the body, and, indeed, the abnormal conditions associated with very many diseases, affect the neurons of the seventh with especial severity. For this reason the expression of the face is of considerable value in diagnosis; the facial muscles are especially liable to the various tics and spasms, and the habitual use of certain muscle groups gives rise to the permanent and characteristic position of the facial tissues which results in the sum of what is called "expression" or character in appearance.

The nucleus of the facial nerve receives association fibers from many sources. Its most conspicuous control is that by the red nucleus and related basal ganglia. It is by this relationship that the various emotional states so greatly affect the facial expressions.

The pyramidal fibers pass to the nucleus directly, though the volitional control of the facial is less absolute than is the volitional control of certain other nerves. The facial muscles may be brought under almost absolute control through constant education. This control is manifest more as a repression of emotional expressions than as increased or modified expressions. This is shown most clearly in the case of those who wish to imitate an expression, as in acting. It is commonly recognized that the volitional imitation of an expression is practically impossible, and that the only way to imitate the expression of an emotion is to imitate the sensation — that is, to actually feel the emotion whose expression is desired. In this way the red nucleus and associated ganglia are brought into control in such a way as to initiate the very stimulation of the structures needed as to bring about the real expression of the emotion sought. This condition must be remembered when one is dealing with those patients in whom

the existence of habitual expressions of ill feelings are manifestly a cause of depression and ill health.

The motor facial nucleus receives fibers from the sensory nuclei of the facial, the trigeminus, the auditory and the vagus nerves.

Axons and collaterals from the fillet carry impulses from the nucleus gracilis and nucleus cuneatus. Axons and collaterals from the posterior longitudinal fasciculus carry impulses from the midbrain and probably from the pontine nuclei. Through these very complex relations the facial nerve is constantly under varying degrees of stimulation and inhibition.

Motor Root of the Trigeminal Nerve

The nucleus of the motor part of the fifth nerve lies in the upper part of the pons and under the floor of the cerebral aqueduct (aqueduct of Sylvius). Its fibers leave the anterior face of the pons, join the larger sensory root of the fifth, and pass with its mandibular division to the muscles of mastication.

This nucleus is also of the viscero-motor series, and its function is now of this order, though the muscles which it innervates are skeletal, striated, and largely under volitional control.

The nucleus of the trigeminus receives fibers from the sensory nuclei of the fifth, and it is through this relationship that the masticatory reflexes are intermediated.

The nucleus of the trigeminal receives fibers of association from the other sensory nuclei of cranial nerves, from the nucleus gracilis and nucleus cuneatus, and from the pyramidal tracts. The red nucleus and other basal ganglia send fibers to this nucleus also. Though this control is not so conspicuous as is the similar control of the facial, yet the forcible tension of the temporal and masseter muscles in certain emotional conditions is indicative of the intensity of the stimu-

lation sent from the basal ganglia centers to the motor nucleus of the fifth.

The constant use of these neurons, as in the case of the facial, renders them susceptible to the ill effects of abnormal reflexes, as in case of trismus, and to the action of certain poisons, as in the case of tetanus and eclampsia.

The Ocular Motor Nerves

The nuclei of the third, fourth and sixth cranial nerves occupy a column extending from the floor of the aqueduct under the superior colliculus to the abducent nucleus in the pons. This column is in the line of the anterior horns of the cord and the hypoglossal nucleus. It is composed of the somatic motor neurons, and it is chiefly somatic motor both in its phylogenetic development and its present function. The different nuclei have certain peculiarities in common. Each of these nuclei exchanges association fibers with every other; each receives fibers from the pyramidal tracts; each receives many fibers from the superior colliculus and the cerebellum; each receives a few fibers from the red nucleus. Each receives also a few fibers from the sensory cranial nerve nuclei and from the nucleus gracilis and the nucleus cuneatus. The different nuclei have certain individual peculiarities.

The nucleus of the abducens lies within the bend of the genu of the facial, and a group of cells near the facial nucleus is included as part of the abducens nucleus. It was originally supposed that these fibers, really from the accessory nucleus of the abducens nucleus, were from the facial nucleus. The very close morphological relationship renders the existence of close associational neurons very probable.

The trochlear nerve lies beneath the inferior colliculus. Its fibers decussate, almost or quite completely, so that the fibers from each nucleus innervate the trochlear muscles of

the opposite side. No explanation has been offered for this phenomenon.

The oculo-motor nerve includes several groups of nerve cells, each of which performs its own function. Besides the somatic motor nuclei, of which a variable number have been recognized, there is a viscero-motor nucleus which requires some attention. The viscero-motor nucleus of the third nerve includes a number of small nerve cells which are homologous with the lateral columns of the cord and the cranial viscero-motor nerve nuclei. Its fibers leave the interpeduncular fossa of the midbrain with the somatic motor fibers of the third, and pass with these to the ciliary ganglion. Here they terminate by forming synapses with the sympathetic cells of this ganglion, and it is the non-medullated fibers of these, passing in the short ciliary nerves, which innervate the ciliary muscle and the constrictor of the pupil.

The viscero-motor nucleus, like the somatic-motor nucleus, receives fibers from the superior colliculus, the other sensory cranial nerve nuclei, the red nucleus, and perhaps the other nuclei of the ocular muscles. It does not receive fibers from the pyramidal tract. This nucleus is of considerable interest in being involved in certain paralyses. It is rather infrequent to find any other viscero-motor nucleus the seat of paralysis. This may be due to the fact that a paralysis of other viscero-motor nuclei would either result in a death so speedy as to preclude the possibility of diagnosis, or the symptoms would be too vague for the correct diagnosis to be made, or it may be that the position of the third nerve viscero-motor nucleus renders it more susceptible to the action of disease conditions than are other nuclei of the visceral column.

CHAPTER VIII

THE SPINAL CENTERS

The spinal cord is to be considered in regard to two chief functions. From the standpoint of the lower vertebrates, the spinal cord is chiefly a series of neuron groups, which are centers for the control of all of the skeletal and visceral structures of the corresponding segment. Later development shows a progressive development of long tracts. These long tracts serve several purposes, all concerned in increasing the efficiency of the central nervous system in its duties in unifying the parts of the body. The long tracts may be afferent, in which case they supply the higher centers with the nerve impulses needful in their functions; or they may be efferent, in which case they carry to the spinal centers the impulses sent out from the higher centers in answer to the action of the impulses transmitted by the afferent tracts; or they may be associational, in which case they enable the different centers, both in the cord and in certain of the higher centers, to act in unity. The spinal centers have retained in great degree their original functions in controlling the structures of the corresponding segments of the body, through all the great development of the long tracts.

The spinal centers are not to be considered, with their present development, at least, to be separate and distinct from an anatomical standpoint. It is not possible to select from the cells of the cord the exact groups concerned in any reaction. It is not possible, at present, to say certainly whether the same nerve cell or group of cells may be concerned in the coördination of the nerve impulses of more than one different

function. There are no facts of interest in this connection except the symptoms produced by certain degenerative processes in the cord, and the results of these observations are, so far, very contradictory.

It is not possible to determine the exact extent of any nerve center. For if any center should extend through several segments of the cord, or if it should be very limited in extent, but should receive axons or collaterals from the sensory roots of several segments, the relations would be identical from a functional standpoint.

From the symptoms observed in cases of disease following injury to the cells in the gray matter of the cord, it appears that the viscero-motor centers extend through several segments of the cord. Yet it is possible that they merely receive association fibers from several adjacent segments. It is possible, then, only to locate these centers rather vaguely — that is to say, that any one is found between a certain spinal segment and another lower spinal segment.

The Spinal Cord

The spinal cord includes that part of the central nervous system which lies within the vertebral canal. Its uppermost extremity is marked by the lower limit of the decussation of the pyramids, and by the uppermost fibers of the origin of the first cervical nerve. It terminates at the lower border of the first lumbar vertebra. The entire length of the cord is about seventeen or eighteen inches, according to the varying heights of individuals.

Below the limit of the cord lies an extension continuous with it, the filum terminale. This resembles the cord for a short distance; it contains fibers and gray matter resembling embryonic nerve tissues. Vestiges of the coccygeal nerve roots are sometimes to be found. The filum terminale reaches down into the sacral region, where it terminates by becoming

continuous with the connective tissue cord formed from the rudimentary meninges, and is attached to the sacrum.

The spinal cord varies in diameter in different regions; it is a little more than a half inch in its largest diameter, and a little less than a half inch in its smallest diameter. Its weight is about one and one-half ounces, avoirdupois.

In form the spinal cord is an irregular cylinder. It presents two swellings. The upper of these is called the cervical enlargement, which corresponds to the area of origin of the nerve roots which supply the arms and shoulder girdle. The lower is the lumbar enlargement, which gives rise to those nerves which supply the pelvic girdle and the legs.

The spinal cord contains at its approximate center a canal called the sixth ventricle, or the neural canal, or the central canal of the cord. It is lined with epithelium, which is ciliated in the embryo.

The Spinal Gray Matter

The gray matter of the cord surrounds this central canal. It is arranged in the form of a very irregular H, whose arms vary in length and breadth in the different areas of the cord. Throughout the thoracic region, and to slight extent in certain other regions, there is found a slight swelling upon the central part of each lateral arm of the H-shaped gray matter. This is called, when present, the lateral horn of the cord (Figs. 35, 36, 37.)

That part of the gray matter which extends forward is called the anterior horn, that which extends backward is called the posterior horn.

The anterior horn includes two classes of cells. The large multipolar cells, which are so conspicuous a feature in cord sections, are the motor cells of the first order; their axons pass by way of the anterior roots to the skeletal muscles and carry the nerve impulses which cause the movements of the skeleton. (Fig. 44.) Associated closely with these cells

are others, smaller and also multipolar, whose axons branch very freely close to the cell, and do not leave the gray matter. These cells (Golgi Type II) are functional in assisting in the coördination and transmission of impulses concerned in reflex actions.

The cells of the lateral horn send axons by way of the anterior roots and the white rami communicantes to the sympathetic ganglia. They carry impulses which are concerned in the control of the viscera and the blood vessels. (Figs. 39, 40, 41, 45.)

The posterior horn includes cells of several functions. In this part of the gray matter are found cells whose axons terminate by branching among the cells of the other parts of the gray matter. These are associational in function. Others of the posterior cells send axons upward and downward through the gray matter or through the tracts of white matter at the edge of the gray, to upper or lower segments. They terminate by entering the cord and forming synapses with different cells at that level.

The nucleus dorsalis (Clarke's column) is found only in the thoracic cord. It sends axons by way of the anterior ascending cerebello-spinal tract and by way of the posterior ascending cerebello-spinal tract to the cortex of the superior vermis of the cerebellum, or to its central nuclei. This tract carries the impulses concerned in muscular sense. Axons from this column of cells probably make up the spino-thalamic tract, which carries impulses concerned in pain and the temperature sense to the optic thalamus.

The white matter of the cord is composed of ascending, descending, and mixed tracts.

Descending Tracts

The descending tracts are as follows:

I. The direct pyramidal tract extends from the medulla

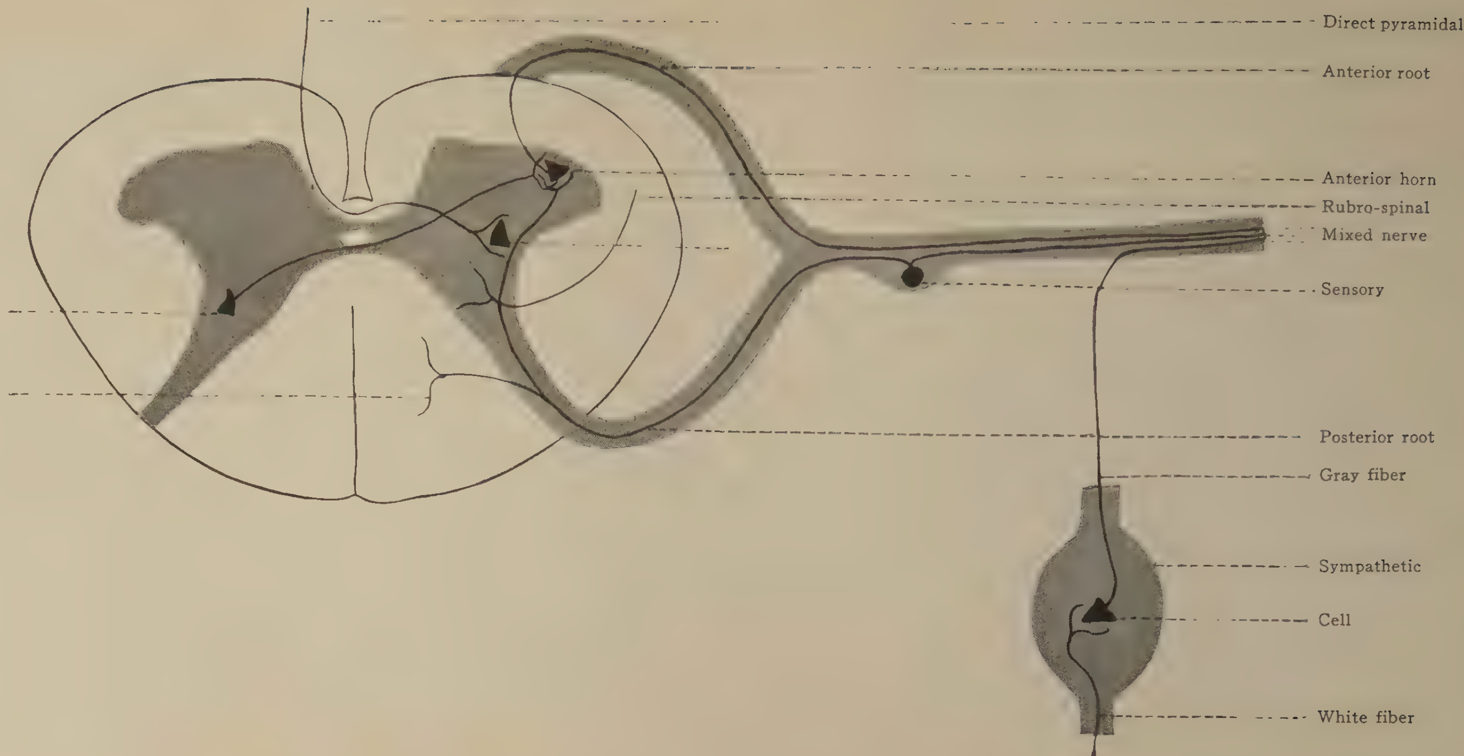


Fig. 41. Control of the brachial muscles.

to the mid-dorsal region. It terminates by forming synapses with the cells in the central region of the opposite spinal crescent. It is composed of axons of the large pyramidal cells of the precentral convolutions of the same side of the cerebral cortex, and it carries impulses concerned in the voluntary movements of the arms and shoulder muscles.

II. The crossed pyramidal tract extends through the entire length of the cord. It terminates by forming synapses with the cells of the gray matter of the central part of the crescent of the same side. The tract is composed of the axons of the large pyramidal cells of the precentral convolution of the opposite side of the cerebral cortex, and it carries the impulses concerned in the voluntary movements of the lower part of the body.

III. The rubro-spinal tract extends through the length of the cord. It is composed of fibers which are axons of the cells of the red nucleus, and probably the substantia nigra and the sub-thalamic region, and it terminates by forming synapses with the cells of the lateral horns and the central gray matter. Perhaps the fibers may pass in part to the anterior horns directly, but this is not certainly known. This tract carries impulses concerned in the emotional and instinctive movements of the skeletal muscles, and in the visceral activities associated with emotional states.

IV. The anterior longitudinal bundle (tecto-spinal tract) extends through the length of the cord. Its fibers are axons of cells in the colliculi, and it terminates with the pyramidal fibers. It is supposed to be concerned in maintenance of the muscular tone, and certainly transmits impulses functional in the coördination of those reflex movements associated with sights and sounds.

V. The olivo-spinal tract is not well known. Its fibers are the axons of cells in the inferior olive, and the impulses are supposed to be concerned in the coördination of the more

complex movements of the body. It is closely related to the cerebellum in function.

VI. The ponto-spinal tracts extend the length of the cord. They are composed of the axons of cells in the reticulum of the pons, which are distributed to the gray matter with the pyramidal tracts. The impulses carried by these tracts are probably concerned in the coördination of the muscular movements and in the maintenance of the tone of the skeletal muscles. The lateral ponto-spinal tract is decussated, the medial tract is not decussated.

VII. The vestibulo-spinal tract has its origin in the vestibular nuclei. It is a rudimentary structure in the higher vertebrates, but represents a connection of great importance in fishes. It forms synapses either with the anterior horn cells, or with cells closely related to these. The impulses carried by this tract are concerned in the maintenance of muscular tone, and the coördination of the movements associated with equilibrium.

VIII. The descending cerebello-spinal tract extends through the length of the cord. Its fibers terminate by forming synapses with the cells of different regions of the gray matter of the cord at different levels. Its fibers are axons from the cerebellum. It is not known whether they are axons of the Purkinje cells or of the cells of the dentate nucleus. The impulses carried by this tract are concerned in maintaining the tone of both skeletal and visceral muscles, and in securing the coördinate activity of the skeletal muscles, especially those concerned in equilibrium. It is not known whether these impulses are greatly concerned in the visceral activities or not. The phylogenetic history of the relations seems to indicate the possibility that this function may be included.

IX. The comma tract, though a descending tract, is derived from the sensory neurons. The entering axons of the sensory neurons divide into two branches, the shorter of which

passes downward in the posterior funiculi for a distance of one or two spinal segments, and terminates by forming synapses with the cells of the lower levels. The impulses thus transmitted are probably concerned in the more complex reflexes, and in securing more perfect coördination of the movements of the skeletal and visceral muscles.

Ascending Tracts

The ascending tracts of the cord include the following:

I. The fasciculus gracilis (tract or column of Goll) lies near the posterior median septum. It is composed chiefly of the axons of the sensory ganglion cells, and a smaller number of axons from the posterior horn cells from below the mid-dorsal region. The fibers pass to the nucleus gracilis in the medulla, where they terminate by forming synapses with the cells of that nucleus. A few fibers of this tract pass directly to the cerebellum by way of the restiform body.

II. The fasciculus cuneatus (tract or column of Burdach) is composed chiefly of the axons of the cells of the sensory ganglia, and partly of a smaller number of axons of cells of the posterior horns. These fibers pass upward to the nucleus cuneatus in the medulla, and form synapses with the cells of that nucleus. A few of the fibers of this tract pass directly into the restiform body and into the cerebellum.

III. There is some reason to consider the existence of a long sensory tract situated in the posterior gray commissure of the cord. This has been called Ciaglinski's tract. Its relations are not known.

IV. The anterior ascending cerebello-spinal tract (Gower's tract) is composed of axons of the cells of the dorsal nucleus, chiefly of the opposite side. With it are carried the fibers of the spino-thalamic tract, which have the same origin. These tracts pass together into the region of the brachium conjunctivum, where the cerebellar part of the tract turns

backward to enter the cerebellum, while the spino-thalamic tract passes onward to the optic thalamus.

V. The posterior ascending cerebello-spinal tract (direct cerebellar) is composed of axons of the cells of the dorsal nucleus, chiefly of the same side. These fibers pass by way of the restiform body to the cerebellum, where they terminate either in the cortex of the superior vermis, or in the central gray matter of the cerebellum, by which the impulses are transmitted to the cortex of the superior vermis.

VI. The median longitudinal bundle is composed of axons of the cells of the anterior horns, and it terminates in the cranial nerve nuclei and the thalamus. It is concerned in the more complex reflex actions.

Mixed Tracts

I. The antero-lateral fasciculus proprius lies next the anterior horn on its lateral aspect. Its fibers are from the cells of the gray matter, and they pass both upward and downward, thus connecting the different levels of the same side of the cord.

II. The antero-median fasciculus proprius lies next the anterior horn on its central aspect. Its fibers pass both upward and downward to a certain extent, but chiefly they decussate in this passing, so that these fibers are concerned in connecting the contra-lateral segments of gray matter, both of the same and of neighboring levels. Within this tract lies the median longitudinal bundle.

III. The posterior fasciculus proprius is made of axons which connect the different levels of the cord. They are mostly short fibers, only a few segments in length. The cornu-commissural tract is the postero-lateral bundle of fibers, which include also fibers concerned in connecting the contra-lateral gray matter, as well as the different homolateral levels of the cord.

The Upper Cervical Group

The centers of the upper cervical cord lie within the gray matter of the first, second, third and fourth cervical segments. The gray matter of this portion of the cord presents certain peculiarities.

These segments occupy the upper part of the cervical enlargement. The posterior horn is capped by the substantia gelatinosa, among whose cells the descending branches of the fifth cranial nerve terminate. The ophthalmic division of the fifth supplies this region especially freely.

The nucleus dorsalis (Clarke's column) is wanting. The intermedio-lateral cell group (lateral horn) is displaced anteriorly, probably because of the development of somatic functions and relations on the part of the cells whose axons make up the spinal part of the eleventh cranial nerve, and of those whose axons make up the phrenic nerve. The trapezius and the sterno-mastoid are innervated by the eleventh cranial, and the diaphragm by the phrenic. These muscles are especially subject to abnormal reflex contractions as the result of excessive viscero-sensory impulses from viscera which are affected by pathological conditions.

The anterior horn is large and broad. It includes several groups of cells. The mesial cell column is homologous with a similar group of cells through the whole extent of the cord, and it innervates the trunk muscles; in the case of the upper cervical group, the superior and inferior oblique, the rectus capitis posticus major and minor, the complexus and trachelo-mastoid, the splenius and semispinalis, the multifidus spinæ, the transversalis cervicalis, cervicalis ascendens, by the posterior primary divisions, the splenius, platysma, scaleni, longus colli, rectus capitis anticus major and minor, rectus capitus lateralis, and the sterno-mastoid in part by the anterior primary divisions. The hyoid muscles also are innervated from

these segments, probably from a small cell group in the antero-lateral column.

These cell groups are intricately associated with the cell groups of the posterior horns, and with the gray matter of neighboring segments. The muscles named above are thus affected by many of the sensory impulses reaching the segments. They are found abnormally contracted in many disorders of viscera, limb structures, and cranial structures.

The antero-lateral cell group is not represented in the thoracic cord, but is well marked in the upper and lower cervicals; the axons of these cells innervate the limb muscles. These cell groups seem to represent a later phylogenetic development than the antero-mesial group; they are larger cells, have long axons, and are poorly associated with the other cell groups of the gray matter. This is, no doubt, the reason why the visceral reflexes have so little effect upon the limb muscles, though they are not altogether free from visceral reflexes, as is commonly supposed. They are very well supplied with association fibers from the sensory neurons innervating the limb muscles, skin and joint surfaces. The muscles innervated by the anterior lateral group are, Levator scapulæ, teres major and minor, supraspinatus, and rhomboid.

The somatic sensory cells of this group lie in the ganglia on the posterior roots of the corresponding nerves. The dendrites of these cells are distributed as follows:

Skin over the back of the neck and the head to the vertex, including the mastoid process and part of the ear; the skin of the neck as far upward as the lower line of the mandible; the muscles innervated by the motor neurons of the same segments; the articular surfaces of the first, second, third, fourth and fifth vertebræ, and the sterno-clavicular and the acromio-clavicular articulations; the meninges of the corresponding spinal segments.

No viscero-sensory neurons are found in these segments,

but the viscero-sensory neurons of the fifth, eighth, ninth and tenth cranial nerves send collaterals and terminals to these segments. The sensory portion of the seventh is not known to send fibers to the cervical cord.

The efferent impulses from these centers are influenced by both inhibiting and stimulating impulses from the following sources:

I. The impulses from the skin, muscles and joint surfaces innervated by the somatic sensory neurons of the same segments affect the efferent impulses from these centers. By this relation the direct reflexes are governed. Under slightly abnormal conditions, such as slight malpositions of the articular surfaces mentioned, the contraction of the muscles may become excessive and constant, and these reflex muscular contractions may in turn send in sensory impulses which increase or decrease the abnormal position of the structural tissues, and the stream of sensory impulses may be further modified.

II. Impulses from the sensory nuclei of the fifth, eighth, ninth and tenth cranial nerves are carried to the upper cervical centers. By this relationship abnormal conditions in the area of distribution of these nerves may cause excessive contractions of the muscles innervated by the upper cervical segments. Thus are produced the tensions of these muscles during toothache, or gastritis, or pharyngitis, or otitis media, or conjunctivitis, etc.

III. Impulses from the nucleus gracilis and nucleus cuneatus reach the upper cervical segments. As a result of this relationship abnormal sensory impulses from diseased viscera may cause abnormal tension of the upper cervical muscles. The tension of the upper cervical muscles so often found associated with diseased pelvic or abdominal organs is thus produced.

IV. Impulses from the cerebellum, the vestibular nuclei, the quadrigeminates, and probably the nuclei of the pontine

reticulum, reach the nuclei of the upper cervical segments. By this means the movements of the upper cervical muscles are coördinated, and their normal tone is maintained.

V. The fibers of the direct pyramidal tract form synapses with the cells of the lateral cell mass of the opposite side, and these in turn send axons to the large motor cells of the anterior horn. Thus the impulses from the precentral cerebral convolution are enabled to carry the impulses concerned in the volitional control of the upper cervical muscles.

VI. The rubro-spinal tract carries impulses from the red nucleus and the neighboring basal ganglia to these segments. By this means the upper cervical muscles are brought under the control of the emotional impulses.

VII. Descending impulses from the viscero-motor centers in the medulla reach the upper cervical segments. By this means the movements of the diaphragm, scaleni, etc., in respiration, and in the modified respiratory movements, as coughing, sneezing, the respiratory factors in speech, etc., are controlled; the diaphragmatic movements in vomiting, defecation, and similar actions are secured.

Lower Cervical Group

This group of centers includes those situated in the fifth, sixth, seventh and eighth cervical segments, and the first thoracic segment of the cord. The gray matter in these segments presents certain peculiarities. The segments named include the lower part of the cervical enlargement.

The posterior horn is capped by the substantia gelatinosa. In this region it is less conspicuous than in the upper cervical group, and it contains fewer nerve cells. There is a difference among neurologists concerning the place of the descending fibers of the fifth; by some authors it is given as reaching as low as the sixth cervical segment, while others consider the

evidence insufficient to show fifth-nerve fibers below the second cervical segment. Reflexes initiated by the stimulation of the fifth nerve affect the action of the centers of the cord as low as the upper thoracic segment, but this may be due to the existence of closely-related association neurons. The lower cervical group evidently receives impulses from the fifth, whether by direct fiber paths or by means of interpolated neurons is not yet apparent.

The nucleus dorsalis (Clarke's column) is found only in the seventh cervical and first thoracic segments. The viscero-motor column is scarcely to be found. A few fibers enter the phrenic from the upper part of the group, and a few assist in forming the spinal portion of the eleventh cranial nerve. Otherwise the column is not represented. The significance of these nerves is discussed in connection with the upper cervical group.

The first thoracic and perhaps the seventh cervical segments contain a few cells of the cilio-spinal center.

The anterior horns of this region are broad and large. The cells are arranged in groups, part of which are placed mesially and a part of which are placed laterally.

The mesial group is homologous with a similar column of cells through the extent of the cord. Its fibers innervate the muscles of the trunk, including the semispinalis and multifidus spinæ, the trachelomastoid, scaleni, longus colli, cervicalis ascendans, transversalis cervicis, complexus, and splenius. The cells in this group represent the older structure, phylogenetically, than the lateral group of cells; their central relations are complex, and they receive impulses from many sources, viscero-sensory, somatic sensory, and descending. The muscles named as being innervated from these cells are, therefore, subject to abnormal contractions as the result of excessive stimulation of the centers from other structures. It is especially noted that these contractions follow visceral dis-

turbances of the cervical and cranial regions, as well as in the upper thorax.

The lateral group of cells includes several groups, whose exact functions have not been certainly worked out. This column is not found in the thoracic region of the cord. Its cells send axons which innervate the muscles of the shoulder girdle and the arms, including the following:

Teres major and minor, supraspinatus and infraspinatus, rhomboid, anconeus, subscapularis, serratus magnus, pectoralis major and minor, coracobrachialis, deltoid, biceps, triceps, brachialis anticus, supinators longus and brevis, latissimus dorsi, the pronators, extensors and flexors of the wrists and fingers, the lumbricales and interossei, and the thenar and palmar muscles.

These cell groups represent the newer structure, phylogenetically; their central connections are not very freely associated with other cell groups, and the muscles named are not especially subject to abnormal contractions from sensory stimulations in other parts of the body.

The somatic sensory cells lie in the sensory ganglia on the corresponding posterior roots. Their dendrites are distributed to the following structures:

Skin over the arms, hands and fingers, and a small area over the anterior and posterior aspect of the thorax, innervated by the first thoracic nerve;

The muscles innervated by the motor neurons of the same segments;

The articular surfaces of the fifth, sixth and seventh cervical and the first thoracic vertebræ, the clavicle, the first costo-sternal, the scapula, the humerus, radius and ulna, and all the articulations of the wrist, hands and fingers;

The meninges of the corresponding spinal segments.

No viscero-sensory neurons are found in these segments, and the only source of viscero-sensory impulses is by way of

the descending fibers of the cranial nerves, and the association neurons of the thoracic segments.

The efferent impulses from these centers are affected by both stimulatory and inhibitory impulses from the following sources:

I. The somatic sensory impulses from the skin, articular surfaces, and muscles innervated from these segments affect the efferent impulses through simple and complex reflex action. Under slightly abnormal conditions, such as malpositions of the articular surfaces, or skin lesions, the contractions of the muscles may become constant and excessive. These muscular contractions may also affect efferent impulses. Since the structures innervated from the brachial plexus are phylogenetically of comparatively recent origin, the central associations are comparatively less complex and the reflexes are less severe and less frequent than in the case of certain other structures.

II. Impulses from the cerebellum, the vestibular nucleus, the olive, the quadrigeminates, and probably the nuclei of the pontine reticulum, reach the lower cervical segments by way of the tracts named after their origin. By these connections the normal tone of the muscles innervated from the brachial plexus are maintained, and their movements are coördinated.

III. Fibers from the direct pyramidal tract of the cord form synapses with the cells of the opposite side of the cord. By this means the voluntary impulses from the precentral convolutions reach the muscles of the opposite upper limb.

IV. The rubro-spinal tract carries impulses from the red nucleus and adjacent ganglia to these segments. Thus the arm movements are controlled by the emotional reactions.

V. Descending impulses from the viscero-motor centers in the medulla, and perhaps the pons and midbrain, reach these segments. The most conspicuous function thus mediated is that of respiration.

CHAPTER IX

THE SPINAL CENTERS (Continued)

Upper Thoracic Group

The centers of the upper thoracic cord lie within the gray matter of the second, third, fourth, fifth and sixth thoracic segments. In part, the uppermost of these centers extend into the gray matter of the first thoracic and the seventh cervical segments. The cells of the lower thoracic centers intrude upon the fifth and sixth segments to a certain extent.

The gray matter of the upper thoracic segments is rather small in extent. The posterior horns are long and slender. The cap of substantia gelatinosa is wanting, or nearly so. The nucleus dorsalis (Clarke's column) is well marked. The lateral horn is well developed. The fibers of its small, multipolar cells make up the white rami communicantes, which leave the cord chiefly by the anterior roots, but also to a certain extent by the posterior roots. The viscero-motor centers are in this part of the gray matter.

The anterior horn is small, with a narrow head. It contains only the column of cells homologous with the mesial cell group of the lumbar and cervical regions. These cells send their axons to innervate the muscles of the trunk, including the following:

Semispinalis dorsi, multifidus spinæ, spinalis dorsi, intertransversales, rotatores spinæ, interspinales, longissimus dorsi, accessorius, levatores costarum, the intercostals of the corresponding segments, serratus posticus, and a few fibers from the fifth and sixth enter the upper part of the external oblique.

The anterior horn cells of this group of segments are of comparatively great age, phylogenetically; they are closely associated with the cells in other regions of the gray matter, and they are thus subject to considerable variation in activity, and to abnormal activity in the presence of excessive sensory stimulation, especially from the viscera innervated from the same segments. The approximation of the ribs over the affected areas in pulmonary tuberculosis is recognized even by physicians who fail to see the relation in its full significance.

The somatic motor centers are governed by impulses from the following sources:

I. Somatic and visceral sensory impulses affect the tone of the muscles controlled from these segments.

II. Descending impulses from the medullary centers, especially the respiratory center, bring about the coördinate movements of respiration, etc.

III. Descending impulses from the cerebellum, vestibular nuclei, centers of the reticular formation, etc., maintain the tone of the muscles and coördinate their action, especially with reference to the maintenance of the erect and symmetrical position.

IV. Impulses from the precentral convolutions of the cerebral cortex carry volitional impulses to these centers. Volitional control of the thoracic muscles is not absolute. The autonomic control is more efficient.

V. Descending impulses from the red nucleus and related ganglia bring the thoracic muscles under the control of the emotional states.

The viscero-motor cells of these segments lie in the lateral horns. Their axons pass, mostly by way of the anterior roots and the white rami, to the sympathetic chain. Their further course must be described with the action of the specific centers.

Cilio-spinal Center

This center includes a number of cells extending from the sixth or seventh cervical segments to the fourth thoracic. It seems to be most fully represented in the neighborhood of the second thoracic segment. This center is controlled by impulses from the following sources:

I. Somatic sensory impulses reaching these segments may affect their activity. This is especially noted in the dilatation of the blood vessels and the pupil of the eye as a result of irritation over the back of the neck and the upper thoracic spines. Bony lesions of this region also produce the same effect.

II. Viscero-sensory impulses reaching the same segment exert a slight effect. This reaction is not always found in animals. It is evident that no tests could be made upon human beings, and the clinic evidence is not sufficiently exact to warrant any statement in regard to the matter.

III. Descending impulses from the quadrigeminates and related centers in the medulla, pons and midbrain affect this center.

IV. Descending impulses from the red nucleus and related ganglia bring the action of the cilio-spinal center under the control of the emotional states. The secretion of tears and dilatation of the pupils in grief and anger, etc., illustrate this action.

The fibers from the cilio-spinal center leave the cord with the white rami of the second and third thoracic anterior roots. They enter the sympathetic cord, and pass without relay to the superior cervical ganglion. (Fig. 40.) Here they break up into many fine branches and enter into the formation of the pericellular baskets of this ganglion. The number of sympathetic cells which are thus controlled is not known. The

axons of the sympathetic cells are non-medullated fibers which pass to the structures of the orbit. Some of them, probably vaso-constrictors, follow the carotid artery and control the size of the blood vessels of the orbital structures. Others reach the semilunar ganglion (Gasserian ganglion) and are distributed with the long ciliary nerves to the orbital structures. None of these fibers have physiological relations with the ciliary ganglion. The structures thus innervated are: the blood vessels of the orbit, the tear glands, the non-striated muscle fibers of the levator palpebrarum, the dilator of the pupil, the non-striated muscle fibers of the capsule of Tenon.

Cranial Viscero-motors

The centers of the control of the cranial blood vessels and viscera are placed in the gray matter of the first, second, third and fourth thoracic segments. The cells may intrude upon the seventh cervical and the fourth thoracic segments. The axons of these cells pass chiefly by way of the anterior roots, but perhaps a few by way of the posterior roots, and the white rami communicantes into the sympathetic cord. These fibers then follow the sympathetic chain to the superior cervical ganglion or to the smaller cranial ganglia, especially those of the carotid plexus. In these ganglia the fibers break up into fine fibrillæ, which enter into the formation of the baskets around the bodies of the sympathetic cells. The axons of the sympathetic cells are distributed partly with the branches of the carotid artery and partly with the cranial nerves to the blood vessels of the cranial structures.

The presence of vaso-motor nerves to the brain has been long in dispute. Late tests seem to demonstrate beyond doubt the existence of vaso-motor nerves to the brain substance. Their existence in the meningeal vessels has been recognized for some time.

Cranial Vaso-motor Centers

The exact relationship between the secretory influence of the cranial nerves and of the centers in the upper thoracic cord has not been demonstrated. The vaso-constrictor control of the salivary, buccal and pharyngeal glands is evidently placed in the upper thoracic cord. The physiology of the dilators, and the secretory action as independent of the vascular control, is yet to be studied.

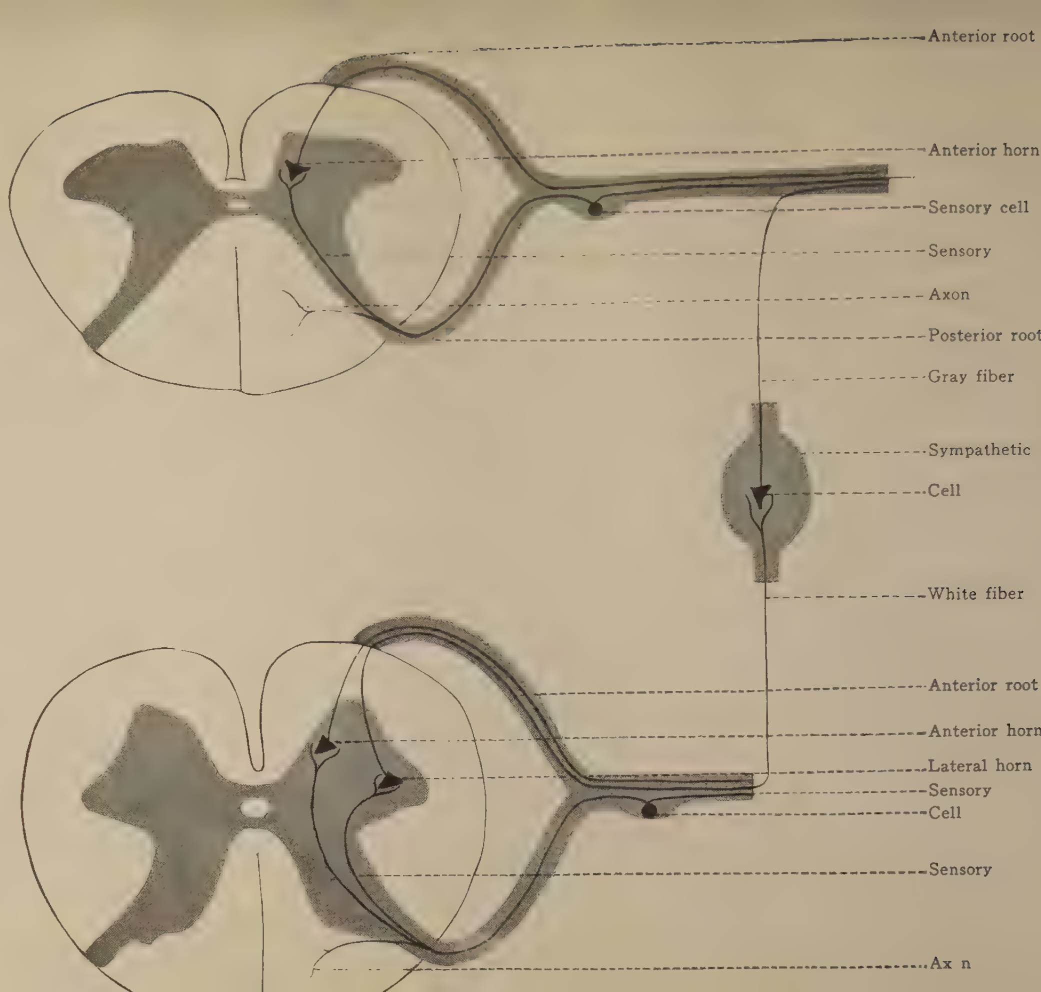
The activity of the centers controlling the circulation through the cranial structures directly is influenced by impulses from the following sources:

I. Descending impulses from the vaso-motor centers in the medulla control the size of the cranial vessels. (It must not be forgotten that the indirect control of the cerebral circulation by changing the general arterial pressure is probably more efficient and active than is the direct action here described.)

II. Sensory impulses from all the structures innervated from the first to the fifth thoracic segments affect the activity of these centers. In this way the bony lesion, the irritation of diseased viscera, and, to a slight extent, the irritation of the skin, may interfere with the circulation through the cranial structures.

III. Descending impulses from the red nucleus, etc., bring the cerebral circulation under the control of the emotional states. Pallor and blushing, the erection of the hair in fright, illustrate this reaction.

Certain facts of clinical finding seem to indicate the possibility that the phenomena of hysteria and related states may depend upon the localization of excessive vaso-constriction in certain brain areas. This seems to be due to unbalanced and excessive activity of the basal ganglia under emotional storms.


Anterior root
Anterior horn
Sensory cell
Sensory
Axon
Posterior root
Gray fiber
Sympathetic
Cell
White fiber
Anterior root
Anterior horn
Lateral horn
Sensory
Cell
Sensory
Ax n

The relationship is not demonstrated, but the possibility should be borne in mind in treating such cases.

Vaso-motors for the Throat Region

The centers controlling the circulation through the structures of the throat lie in the second, third, fourth and fifth thoracic segments. They may intrude upon the first and sixth thoracic segments. The axons of the lateral horn cells concerned in the action of these centers leave the cord chiefly by way of the anterior roots and enter the thoracic cord. The individual fibers follow the cord until they reach the middle or superior cervical ganglion. Here they form synapses with the cells of these ganglia. The gray fibers, axons of the sympathetic cells, pass with the cranial nerves to the area of their distribution. For the most part they are associated with the sensory nerves; rarely they follow the purely motor branches. The blood vessels of the visceral muscles, the glands, the skin, and the skeletal muscles of the neck and throat are thus innervated.

The centers just mentioned are influenced as follows:

I. Descending impulses from the vaso-motor centers in the medulla exert the most pronounced influence upon them.

II. Sensory impulses from the somatic and the visceral structures innervated from the same segments affect their action to a certain extent. This relation is especially noticeable in connection with the pharyngeal and laryngeal tissues, as they are affected by abnormal muscular contractions of the upper thoracic posterior spinal muscles, and by slight malpositions of the upper thoracic vertebræ or by the first and second ribs. Hyoid malpositions are also often concerned in affecting the activity of the centers controlling the throat structures.

III. Descending impulses from the red nucleus and asso-

ciated ganglia affect the action of these centers. Thus the emotional states may be responsible for dilatation of the vessels of the cervical tissues, especially of the laryngeal tissues. The thyroid seems sometimes to be greatly affected in this way.

Glands of the Neck and Throat

The control of the secretions of the thyroid, parathyroids, and other glands of the cervical region is not exactly known. The few facts of clinical and experimental evidence seem to indicate that secretory nerves follow the paths and have the central connections of the vaso-motors.

The Brachial Viscero-motor Centers

The centers for the control of the circulation through the upper limbs and the shoulder girdle are found in the gray matter of the second, third, fourth, fifth and sixth thoracic segments. The cells may extend into the first and the seventh thoracic segments. Rarely there is found evidence of cells capable of affecting the circulation through the arms as low as the eighth thoracic or as high as the seventh cervical segments.

The fibers concerned in this function leave the spinal cord by way of the anterior roots of the third, fourth and fifth segments, chiefly, and enter the sympathetic cord. (Fig. 42.) They pass without relay to the ganglion stellatum, rarely to the middle cervical ganglion. They terminate by entering into the formation of the pericellular baskets of the sympathetic. The gray fibers, the axons of these sympathetic cells, pass as gray rami communicantes to the nerves of the brachial plexus. They are distributed with these nerves to the muscles, bone and bone marrow, articular surfaces, and skin of the shoulder girdle, arm, wrist, hand and fingers. No vaso-

motors are found in the palmar surfaces of the tips of the fingers, and they are scantily supplied to the palms.

The action of these centers is affected by impulses from the following sources:

I. Descending impulses from the vaso-motor centers in the medulla.

II. Sensory impulses from the structures innervated from the same spinal segments. Thus visceral irritations may somewhat affect the circulation through the hands, especially, and malpositions of the upper and midthoracic vertebræ may cause phenomena similar to the symptoms of Raynaud's disease, if not identical with them.

III. Descending impulses from the red nucleus and other basal ganglia affect these centers. Thus the circulation through the upper limbs may be affected by emotional states, and the hairs of the arms, especially, may be erected through the action of the pilo-motors.

IV. These centers are affected through association cells in such a manner that during the active contraction of the muscles the circulation through them is greatly increased. Whether this reaction is due to dilators or the inhibition of constrictors, or whether it is caused through segmental reflexes or through the activity of the general vaso-motor centers, is yet doubtful.

Cardiac Accelerator and Vaso-motor Centers

The centers concerned in increasing the rate and force of the heart's beat are placed in the lateral horns of the gray matter of the second, third, fourth and fifth thoracic spinal segments. Perhaps the cells of the first and the fifth may be concerned in the same function to a certain extent. The fibers from these cells leave the cord chiefly by the anterior roots and pass as white rami communicantes into the sympathetic chain. The fibers pass without relay to the cervical region,

where they terminate by forming synapses with the cells in the superior, or the middle, or the inferior cervical ganglion. From these ganglia the gray fibers, axons of the sympathetic cells, pass to the trunk of the vagus nerve, and with that nerve they reach the cardiac plexus. It is not probable that the fibers from the sympathetic form synapses with intrinsic cells of the cardiac ganglia, though this has not been certainly determined.

The blood vessels of the heart probably receive vaso-motor fibers by the same pathway. The existence of vaso-motor fibers to the cardiac vessels has not been experimentally demonstrated, but certain clinic phenomena seem to indicate that they are present, and that they are derived from the spinal segments and carried by the path already described.

The cardio-spinal centers are influenced by impulses derived from the following sources:

I. Descending impulses from the chief cardiac center in the medulla. The action of the accelerators and the inhibitors of the vagus is thus coördinated.

II. Descending impulses from the vaso-motor center in the medulla. In this way the arterial pressure is maintained at an equable height during health, and the tendency is to bring it to the normal height in disease.

III. Descending impulses from the red nucleus and related ganglia. By this means the emotional reactions exert a very profound influence upon the heart's action.

IV Sensory impulses from the heart itself and other structures innervated from the corresponding spinal segments. By this means the sensory impulses from disordered viscera innervated from the same or adjacent segments, or from joint surfaces abnormally placed, or from abnormally contracted muscles, may initiate abnormal functions of the cardiac muscle, and probably at times abnormal dilatation or constriction of the cardiac vessels.

Pulmonary and Pleural Vaso-motors

The centers governing the blood vessels of the pleura and the lungs lie in the lateral gray matter of the first, second, third, fourth, fifth, sixth, and perhaps the seventh thoracic segments. The relationships experimentally determined indicate a tendency to a segmental innervation of these blood vessels, and this segmentation is more noticeable in the pleura than in the lung substance.

The axons of the cells of these centers leave the cord chiefly by the anterior roots, proceed as white rami into the sympathetic cord, and terminate within the ganglion stellatum or the lower or the middle cervical ganglion by entering into the formation of the pericellular baskets of the sympathetic. The axons of the cells thus surrounded pass in part by way of the vagus and in part by way of the aortic plexus to the blood vessels of the pleura and the lungs.

The centers are under the influence of nerve impulses from the following sources:

I. Descending impulses from the vaso-motor center in the medulla.

II. Descending impulses from the respiratory center in the medulla.

III. Descending impulses from the red nucleus and the other basal ganglia.

IV. Sensory impulses from the lungs and pleura, and from the other visceral and the somatic structures innervated from the same spinal segments. In this way the bony lesions are often concerned in the initial disturbance of the circulation, and the infection of the injured area becomes probable.

It is not to be forgotten that the control of the pulmonary circulation indirectly through changes in the tension of the systemic arterioles is probably more efficient than the action of the direct vaso-motor control here described.

CHAPTER X

THE SPINAL CENTERS (Continued)

Lower Thoracic Group

The centers of the lower thoracic cord lie in the gray matter of the seventh, eighth, ninth, tenth, eleventh and twelfth thoracic and the first lumbar segments. In part the cells of the uppermost of these centers extend into the sixth and fifth thoracic segments, and in part the cells of the lowermost of them may extend below the level of the second lumbar segment.

The gray matter of the lower thoracic spinal cord is rather small in extent. The posterior horns are long and rather slender. The lateral horns are well marked. The dorsal nucleus (Clarke's column) is a conspicuous cell mass in the root of the posterior horn. The anterior horn is small.

The anterior horn includes the cell columns of the mesial groups. Their axons leave the cord at its anterior roots, and pass without relay to the following muscles:

Longissimus dorsi, multifidus spinæ, accessorius, latissimus dorsi, quadratus lumborum, pyramidalis, cremaster, psoas major and minor, the corresponding intercostal and interchondral muscles, and the abdominal muscles.

The spinal centers controlling the activities and the nutrition of these muscles are influenced by impulses from the following sources:

I. Somatic and visceral sensory impulses affect the tone of the muscles through reflex action. The contraction of the abdominal muscles in the presence of inflammation involving the abdominal viscera is a familiar example of this reaction.

Less well recognized is the contraction of the deeper spinal muscles under the same conditions.

II. Descending impulses from the medullary centers affect these muscles. This reaction is noticed in the respiratory movements, and in the movements of vomiting, etc.

III. Descending impulses from the cerebellum, vestibular nuclei, pontine centers, olive, etc., assist in maintaining the tone of these muscles, and in coördinating their action. This seems to have special reference to the needs of the body in maintaining the equilibrium of the erect position of the body.

IV. Descending impulses from the precentral cerebral convolutions bring these muscles under a certain amount of volitional control. This control is not nearly absolute.

V. Descending impulses from the red nucleus are carried by way of the rubro-spinal tract. In this way the movements of the lower thoracic groups of somatic muscles are brought under the control of the instinctive and emotional states.

The abdominal muscles are peculiarly subject to a loss of their normal tone. This lack of tone may be due to a number of causes already recognized, such as excessive fat, pregnancy, tumors which greatly increase the size of the abdomen, etc. In addition to these causes of diminished tone is another not so well recognized. Since the tone of muscles is maintained through the incoming sensory impulses, acting both directly and indirectly through the intermediation of the higher centers, it is evident that the lack of the normal sensory stimulation may result in a lack of the normal tone of the muscles so affected. Now the abdominal muscles and the intercostals represent a very primitive structure, and the nerves and nerve centers concerned in their action represent very primitive nerve relations. The so-called higher centers, those concerned in the functioning of the more lately developed structures of the body are chiefly related to the muscles more lately developed.

The trunk muscles are all of this primitive relationship, but only the abdominal and perineal muscles are so placed in the body as to be greatly injured, or at least as to cause the injury of other tissues, even if they do become asthenic. The abdominal muscles, important for the support of organs often abnormally heavy, are placed at a disadvantage on account of the erect position of mankind. So long as the normal nerve impulses are carried into the spinal centers, and so long as the normal efferent impulses reach the abdominal muscles, they retain their normal tone — that is, of course, in the absence of traumatic or other physical forces. But if the lower thoracic spine becomes stiff, as it does in the presence of certain abnormal positions of the vertebræ, or if the ribs become less movable than is normal, then the spinal centers lack the sensory stimulation normally received from the joint surfaces and the changing muscle tension. Thus is produced the lack of normal tone. In the limb muscles, related as they are to the cerebellum and other higher centers, this loss of tone is not so serious. In the case of the spinal and intercostals, the loss of tension is not associated with so serious changes in the position of the underlying viscera, and the symptoms are not so serious.

Even in those cases in which the commonly recognized causes of atonic abdominal muscles are certainly effective in the etiology the atony may be made the greater by the abnormal spinal condition, and the return of the normal condition of the muscles may be facilitated by corrective measures and by such exercises as increase the mobility of the lower thoracic spine.

Lower Thoracic Visceral Centers

The visceral efferent fibers of the lower thoracic cord present certain peculiarities. The axons of the cells of the lateral horn pass in part by way of the white rami fibers into the sympathetic chain, and terminate therein by forming syn-

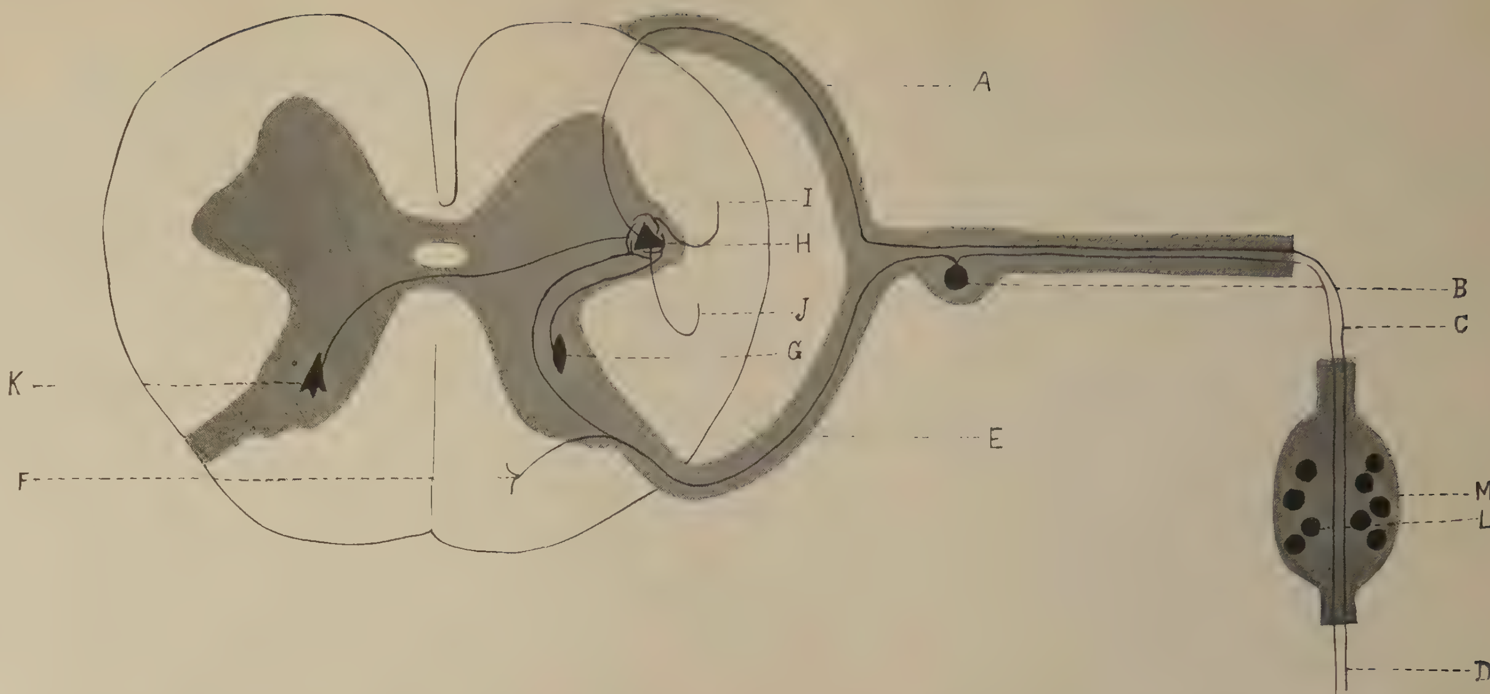


Fig. 43. Control of the splanchnic nerves. A—Anterior root, showing only a white ramus fiber. B—Sensory ganglion cell. C—White ramus fiber, passing through sympathetic ganglion without interruption. D—Efferent ramus from sympathetic ganglion, containing sensory fiber and fiber from lateral horn cell, both medullated. E—Posterior root, containing only viscero-sensory fiber. F—Division of sensory root fiber. G—Cell in posterior horn of cord. H—Cell in lateral horn of cord. I—Descending fiber from medullary center. J—Descending fiber of rubro-spinal tract. K—Cell of contra-lateral posterior horn. M—Cell of sympathetic ganglion. Axons of these cells pass with the splanchnics.

apses with the sympathetic cells; and in part they pass through the sympathetic ganglia directly to the great plexuses of some of the ganglia of the abdominal cavity, or to some of the smaller ganglia on the walls of the intestines, etc. The great bundles of fibers which pass directly to the great plexuses are called splanchnics. They include in their bundles many non-medullated fibers from the ganglia of the sympathetic chain, but they are chiefly composed of the medullated fibers, partly from the lateral horn cells, and partly from the sensory ganglia of the posterior roots. (Fig. 43.)

The great or upper splanchnic nerve contains fibers evidently from the fifth, sixth, seventh, eighth, ninth and tenth thoracic ganglia, but fibers from all the upper thoracic segments may be traced into it. It passes directly to the semilunar ganglia, where some of its fibers terminate in the sympathetic pericellular baskets, while others pass into lower plexuses, where they either terminate in ganglia, or, as in the case of the sensory fibers, innervate the tissues directly.

The middle splanchnic nerve arises in like manner from the tenth and eleventh thoracic segments. Fibers of this nerve may arise from segments as high as the sixth. It passes to the solar plexus, but many of its fibers enter the renal plexus.

The lower or least splanchnic nerve arises evidently from the twelfth or the eleventh and twelfth ganglia. Really, the fibers are the axons of lateral horn cells from the ninth to the twelfth thoracic segments. The lower splanchnic nerve passes to the renal plexus. Its fibers terminate in the smaller ganglia, by forming synapses with the sympathetic cells, or, in the case of most sensory fibers, pass without relay to the tissues innervated.

The Spinal Gastric Center

The pathways of the nerve impulses which control the movements, secretion and circulation of the stomach are not

exactly traced. A few facts only are known, experimentally, and these are supported only in part by clinical evidence. Probably the experimental evidence is not in harmony with the clinical facts because in the presence of disease of the digestive tract the nutrition of the nervous system as well as of the rest of the body is impaired, and the reactions normally characteristic of the centers concerned may be absent, or faulty.

It is known that the impulses from the spinal gray matter of the fifth, sixth and seventh thoracic segments, and probably also from the fourth and eighth, reach the stomach and modify its movements, secretion and circulation. It is known also that lesions affecting these segments are often associated with abnormal conditions of the gastric muscles, secretions and blood vessels. The puzzles are found in the effort to trace these relations further.

Direct stimulation of the upper splanchnic nerve inhibits the gastric movements, and causes vaso-constriction. In some instances the quantity of the secretion seemed to be lessened, in some cases diminished. Stimulatory movements applied to the tissues in relation with the corresponding segments are followed by increased gastric movements. Lesions involving all of these same segments are usually associated, clinically, with gastric dilatation, symptoms of vaso-dilatation, and hypochlorhydria, while in other cases the lesions involving individual vertebræ and ribs are associated with gastritis and hyperchlorhydria. Many tests seem to indicate that the amount of carbon dioxid within the gastric and intestinal tract, and also the amount dissolved in the blood in the vessels, may affect the character of the reaction following certain forms of stimulation.

We can now accept the view that these centers do control, in part, the muscles, vessels and glands of the stomach, but must leave for further investigation the explanation of the apparently contradictory phenomena.

The spinal gastric center may be affected by impulses from the following sources:

I. The visceral afferent impulses from the entire digestive tract may affect the activity of the stomach, either by direct reflex action or by descending impulses from higher centers, or by the association tracts in the cord.

II. Somatic afferent impulses may affect the gastric center, as is shown in the effects produced upon the gastric activities by abnormally contracted muscles innervated from the same segments, by vertebral malpositions, by abnormally placed ribs or other structural tissues. The gastric musculature is usually atonic when the abdominal muscles are atonic, but whether both faults are due to the same cause, or whether either is due to the existence of the other, is not known. The first condition is certainly true at times, and if the gastric muscles should become atonic doubtless the abdominal muscles would suffer eventually. There is no doubt that the loss of the abdominal tone is followed by gastric atony in time.

III. Impulses from the medullary centers control the action of the spinal gastric center.

IV. Impulses from the red nucleus and related ganglia affect the spinal gastric center. This is shown in the hastening of the digestive activities under the joyous emotions, in the sudden inhibition of the digestive activities under fright, grief, or shock, and in the vomiting in urgent disgust. No explanation can now be offered for these different reactions.

V. The activity of the gastric spinal center seems to be affected in noteworthy degree by the character of the blood flowing through it, and the physiological effects of the visceral afferent impulses, or the character of the visceral afferent impulses, seem to vary according to the quality of blood circulating around the sensory nerve endings in the visceral walls.

The Spinal Splenic Center

The centers controlling the splenic muscles and blood vessels lie within the lateral gray matter of the sixth, seventh and eighth thoracic segments of the cord, and perhaps the fifth and ninth segments. The action of the splenic muscle is of considerable interest, since it appears to exert a certain influence upon the abdominal blood pressure and supply. Stimulation of the splenic nerves causes contraction of the muscle of its capsule, and when the capsule is cut, so that the influence of its contraction may not greatly affect the caliber of its vessels, stimulation of the splenic nerves is followed by vasoconstriction.

The action of the splenic centers is affected by impulses from the following sources:

I. Afferent impulses from the somatic tissues affect its action — stimulating movements cause the contraction of the splenic muscle. Lesions of the vertebræ and ribs of the corresponding segments, and abnormal contractions of the muscles innervated from these segments, are associated with abnormally large spleens. In the latter case, if the lesions are the only cause of the enlargement, the spleen decreases very quickly under corrective treatment. This statement does not, of course, apply to those cases in which causes of splenic hypertrophy are present.

II. Probably the action of the splenic muscle is governed, in part at least, by descending impulses from the higher centers, and by visceral afferent impulses, but nothing is certainly known of this relationship.

Spinal Hepatic Center

In dealing with the nerve centers controlling the action of the liver it is necessary to remember the varied functions of that organ. As in the case of the other thoracic and abdom-

inal organs, the action of the vagus is concerned, as well as of the spinal centers. In the case of the liver this relationship is very complex.

The following relations have been demonstrated:

The spinal hepatic center lies in the lateral gray matter of the sixth, seventh, eighth and ninth thoracic segments, and probably in the fifth, tenth and eleventh segments to a certain extent. The fibers which are the axons of these cells pass in part as white rami to the ganglia of the lateral chain of the sympathetic, and in part as the white splanchnic fibers to the semilunar ganglia and the ganglia of the coeliac plexus. The gray fibers which are the axons of the sympathetic cells innervate the hepatic vessels — the arterioles of the portal and hepatic veins and arteries, and to a certain extent the smaller and larger branches of these vessels. They innervate also the liver cells, the walls of the bile ducts, the gall bladder, the hepatic and cystic ducts and the communis choledochus.

The nerve impulses to the liver cells seem to affect the secretion of bile and the glycolytic and glycogenic functions of the liver, but the nervous relations of the formation of uric acid and urea have not been demonstrated.

The spinal hepatic center is affected by impulses from the following sources:

I. Impulses from digestive and other viscera by way of the visceral afferent nerves reach the hepatic center.

II. Impulses from the somatic sensory nerves reach the hepatic center. This is shown in the effects produced upon the liver and the gall bladder by lesions of the corresponding and neighboring vertebræ and ribs. Since gallstones are sometimes found, evidently caused by malpositions of these bones and the structural tissues associated with them, it is supposed that probably the secretions, either of the quality of the bile itself or the amount of mucus, etc., in the glands of the gall bladder, may be affected from the action of the center as

affected by the somatic sensory impulses. This relationship has not been subjected to experimental tests, as yet.

III. Descending impulses from medullary centers, from higher and from lower segments of the cord, may affect the activities of the cells in the hepatic center.

IV. Descending impulses from the red nucleus and associated basal ganglia affect the action of the hepatic center. This is seen to affect the action of the muscular walls of the ducts carrying the bile, as in the jaundiced appearance of some persons for a day or two after having suffered the storms of anger, fright, or excitement of any kind.

Centers for the Intestines

Probably it is logical to think of a series of centers for the control of the circulation, secretion and movements of the intestines. These are arranged in somewhat of a segmental manner, and involve the lateral gray matter of the lower thoracic and the upper lumbar part of the cord.

The axons of the lateral horn cells pass in part as white rami communicantes to the ganglia of the lateral chain of the sympathetic, and in part as the white fibers of the splanchnic nerves, especially the upper and middle splanchnics, to the ganglia of the solar, coeliac, mesenteric and peripheral plexuses. The gray fibers, axons of the sympathetic cells, carry the visceral afferent impulses to the glands and muscles of the intestines, and to the blood vessels.

The spinal intestine centers are influenced by impulses from the following sources:

I. Impulses from the digestive tract are carried to these centers by the visceral afferent nerves. The action of the entire digestive tract in its secretion, muscular activities and circulation is thus in part kept unified through direct reflex action.

II. Sensory impulses from somatic structures are car-

ried to these centers by the somatic efferent nerves and perhaps also by the interpolated association neurons. This relationship is illustrated by the atonic condition of the intestinal wall, the lack of intestinal secretions, and the deficient tone of the intestinal blood vessels so often found associated with those vertebral abnormalities which prevent the normal stream of nerve impulses from the joint surfaces and the sequence of relaxation and contraction of the deeper spinal muscles. If the spinal column be abnormally stiff, if the mobility be decreased, these sensory impulses must also be decreased, and these activities of the centers which depend upon the stimulation afforded by the sensory impulses must necessarily be lessened, unless compensatory activities be initiated in other parts of the nervous system.

III. Descending impulses from the medulla, from the higher spinal centers, and ascending impulses from the lower spinal centers in functional relationship, affect the action of the centers controlling intestinal action.

IV. Descending impulses from the red nucleus and related ganglia bring the action of the intestines under the control of the emotional states, to a certain extent.

V. The character of the reactions affecting the activity of these centers seems to be somewhat affected by the character of the blood flowing through the center in question. The character of the visceral afferent impulses seems also to be affected by the quality of the blood circulating through the viscera and around the nerve endings. This consideration seems to be especially concerned with the carbon dioxid content of the blood. Certain irritants and poisons also may affect the action of these centers.

The Renal Center

The kidneys are not known to have any secretory nerves. The action of their secretory cells seems to depend upon the

speed of the blood stream, and to a certain extent upon the capillary pressure. The vaso-motor nerves to the kidneys thus control their secretion in part, and in part the variations in the general blood pressure and the quality of the blood itself are efficient in modifying the activity of the kidneys.

This center lies in the lateral horn of the tenth, eleventh and twelfth thoracic segments, and probably also in the ninth thoracic and the first lumbar segments. The association tracts bring impulses from segments placed both higher and lower than those mentioned.

The activity of the renal center depends in part upon nerve impulses from the following sources:

I. Somatic afferent impulses from the muscles, joint surfaces, skin, etc., innervated from the same segments or neighboring segments, may affect the action of the renal center. Through this relation the renal effects of bony lesions are manifest.

II. Visceral afferent impulses may affect the action of this center. This has not been experimentally demonstrated. The changes in blood pressure effected by visceral sensory impulses would in themselves affect renal activity; whether the direct reflexes would be concerned or not is not known.

III. Since there is so great increase in the amount of urine excreted after emotional storms and in hysteria, it seems probable that the renal center may be affected by descending impulses from the basal ganglia; but this reaction may be associated with the changes in general blood pressure rather than with any direct effect upon the renal center.

The Pancreas

The centers which control the circulation and the secretion of the pancreas have not yet been well demonstrated. The circulation has been modified experimentally by stimulation of the upper splanchnics, and by tension upon the artic-

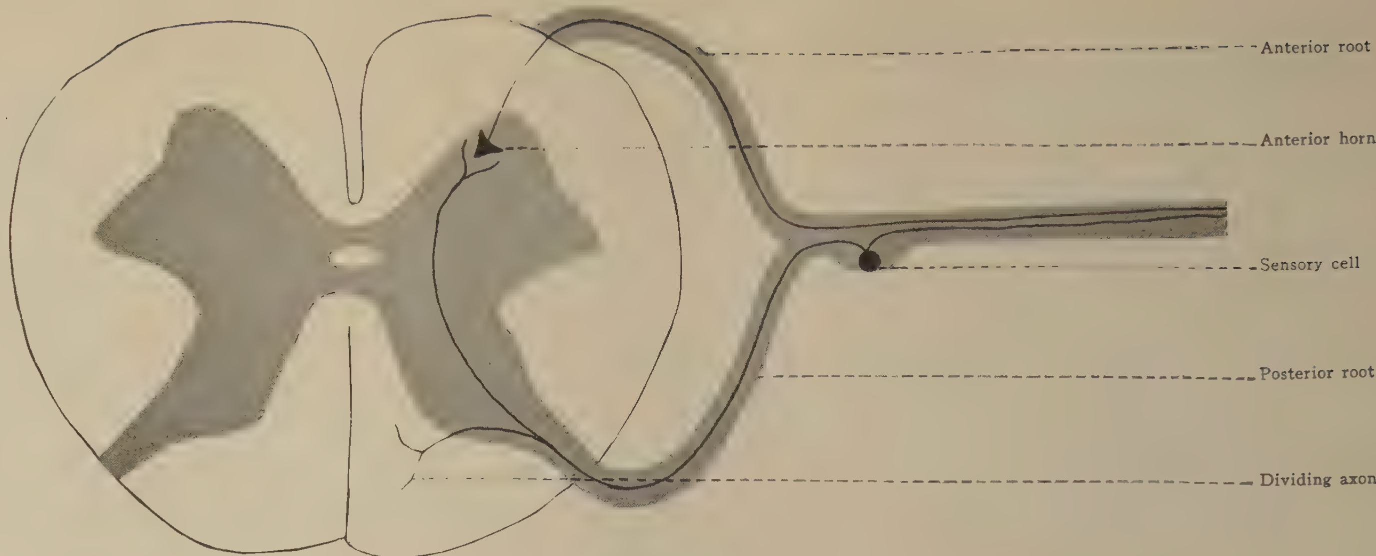


Fig. 44. Simple somatic reflex arc.

ular surfaces of the ninth and tenth vertebræ. Stimulating movements to the spinal column in the region of the ninth and tenth thoracic spines is followed by constriction of the pancreatic vessels. Whether the pancreatic secretions, external and internal, are controlled by either the vagus or the splanchnic nerves is yet to be demonstrated. The study of the nervous control of the pancreas is of especial interest on account of the relation between its internal secretion and the symptoms of diabetes mellitus.

The Reproductive Glands

The circulation through the ovaries and the testes is controlled from the lateral gray matter of the eleventh and twelfth spinal segments, probably including also some of the cells of the ninth and tenth thoracic and the first lumbar segments. Secretory control is not known, nor is the effect of nerve impulses upon ovulation demonstrated. The circulation through these organs may be modified by emotional states. Erotic mental states may be effective in producing sufficient vascular disturbance to be of etiological importance in diseases of the organs, and under certain circumstances the fact of the erotic wise rational. The place of the bony lesion in etiology is recognized.

The Suprarenal Capsules

The suprarenal capsules are known to have both secretory and vaso-constrictor nerves derived from the eleventh and twelfth thoracic and the first lumbar segments. Probably the cells of the tenth thoracic and the second lumbar segments may be included in the center. A recent report from the laboratory of physiology of Harvard shows the internal secretion of the suprarenals to be increased under emotional excitement.

CHAPTER XI

THE SPINAL CENTERS (CONTINUED)

The Lumbo-sacral Group

Below the second lumbar segments the spinal cord shows certain peculiarities, the result, evidently, of the processes of cephalization and of adaptation to the requirements of those organs not subject to the process of cephalization to any great extent.

The progressive loss of the lower spinal segments, the tendency of the controlling centers to become superseded by the increasing efficiency of the cephalad nerve centers, the constant crowding of the visceral centers by the development of the leg-muscle centers, and the simultaneous rearrangement of the connections within the spinal gray matter, all add to the lumbo-sacral cord something of the complexity of relationship found in the medullary centers.

In these segments of the cord the gray matter is arranged in the form of a very short, broad *H*. The anterior horns contain several cell groups arranged in columns. The mesial cell group includes at least two columns. The axons of these cells innervate the trunk muscles. The lateral cell group of the anterior horn is divided into two, three or four columns by different authors. The axons of these cells innervate the muscles of the lower limbs. The lateral horn is not recognizable in the second, third and fourth lumbar segments, but the viscero-motor functions seem to be performed by the cells lying in the lateral portion of the broad *H*. The fifth lumbar

segment begins to show the lateral horn structure, and the sacral segments display the lateral horn cells as the origin of the nervus erigens.

The posterior horns of the lumbo-sacral segments contain a number of small cells, such as are found in the posterior horns throughout the spinal cord. The dorsal nucleus (Clarke's column) is wanting.

The axons of the cells of the mesial group columns of the anterior horn innervate the following muscles: Multifidus spinæ, interspinales, psoas major and minor, gemelli, glutei, obturators, pyriformis, and the lower parts of the abdominal muscles.

The axons of the cells of the antero-lateral columns supply the muscles of the thigh, leg, foot and toes.

The location of the cells which supply a number of the pelvic muscles is not exactly known. They seem in part to be homologous with somatic muscles and in part with muscles of visceral function. Since no white rami or homologous nerve fibers are found in the lumbar region below the first lumbar, or at most the second, and only the nervus erigens is found in the sacral segments, it is evident that the phylogeny of the muscles named below needs considerable study. The muscles supplied from the lumbo-sacral segments in this manner are:

Cremasters, sphincters ani, levator ani, coccygeus, compressor urethræ, ischio-cavernosus, bulbo-cavernosus, transversus perinei, sphincters vesicæ, and the sphincter vaginæ.

The centers controlling the muscles first mentioned, as well as those of the thigh, leg, foot and toes, receive impulses from the following sources:

I. Descending impulses from the precentral convolution of the cerebral cortex affect the activities of all the muscles named, but chiefly those of the lower limbs.

II. Descending impulses from the cerebellum, vestibular

nuclei, olive, quadrigeminates, medullary centers and the centers of the reticular formation, maintain the normal tone of all the muscles innervated from these segments, and coördinate their action in such a way as to secure equilibrium and to provide for the delicacy of certain movements, notably those employed in walking, running, etc.

III. Descending impulses from the red nucleus and associated centers bring these muscles under the control of the emotional states.

IV. Somatic sensory impulses from the skin, muscles, joint surfaces, etc., innervated from the same segments of the cord, assist in the maintenance of the muscular tone, in the simple reflex actions, and in part in the control of the centers which are apparently of viscero-motor function. The somatic sensory impulses from joint surfaces abnormally related, abnormally contracted muscles and the like, may bring about abnormal contractions or the loss of the normal tone of the muscles innervated from the mesial cell groups, and of the muscles of the sphincters.

V. Visceral sensory impulses may affect the activity of these centers. The abnormally contracted muscles found associated with diseases of the pelvic viscera are produced through the intermediation of these reflexes.

VI. Descending impulses from the medullary visceral centers coördinate the activities of the lumbo-sacral centers with the activities of other nerve centers.

VII. Ascending and descending impulses from the lumbar and sacral centers concerned in the coördination of certain complex acts affect the centers governing the muscles named.

The Ano-spinal Center

This center is concerned in the control of all the structures involved in defecation. The exact location of the nerve cells is not known, beyond that it lies in the lumbar enlarge-

ment. (Fig. 46.) Both stimulatory impulses to the muscular fibers of the lower bowel and inhibitory impulses to the anal sphincters are sent from this center, mostly by way of the descending tracts of association and the third and fourth sacral nerves or through the white rami of the first lumbar segments, the sympathetic ganglia and the inferior mesenteric and hypogastric plexuses. Impulses are sent upward also to thoracic centers for the stimulation of the abdominal and thoracic muscles.

The ano-spinal center is controlled by impulses from the following sources:

I. Sensory impulses are received from the region of the rectal and anal tissues, by means of which the normal impulses of defecation are aroused.

II. Sensory impulses are received from neighboring tissues, by means of which defecation movements may be inhibited, or at times initiated in the absence of the normal stimulation. This relation is evident under abnormal conditions, as in vaginal abnormalities, hemorrhoids, and other irritations of the region.

III. Sensory impulses, mostly inhibitory in effect, may reach the center from the somatic structures. This relation is seen in the effects of lesions of the peri-anal tissues, and especially in the effects of malpositions of the lumbar vertebræ.

IV. Descending impulses from the cerebral cortex seem to act in a rather complex manner. First, the descending volitional impulses cause excessive contraction of the external muscles, including the glutei, etc. The sensory impulses from these muscles assist in the inhibition of the action of the ano-spinal center. The pressure exerted upon the descending column of feces by volitional contractions of the skeletal muscles probably lessens the sensory impulses reaching the center from the rectal membrane. Perhaps the descending inhibitory impulses act directly upon the ano-spinal center,

though it is not yet possible to demonstrate this manner of control.

Descending impulses from the cortical centers may assist in stimulating the ano-spinal center to a certain extent. This relation is used in the attempt to establish the "habit" control by directing the patient to go to stool at certain times of the day, and to attempt to perform the act of defecation by using the abdominal muscles, etc., as in the normal act. This attempt brings about the stimulation of the nerve cells which control the skeletal muscles. Since the relationship between these cells and those concerned in the autonomic centers is very intimate, the stimulation of the defecation center is probably secured. This attempt to secure normal defecation is logical only when efficient causes of the abnormal function have been or are being removed. As in the case of the descending inhibitory impulses, we must recognize the possibility of a direct stimulation of the cells of the ano-spinal center from the cerebrum, though this must not be held as demonstrated, and now appears extremely unlikely.

V. Descending impulses from the cerebellum, quadrigeminates, olive, and the medullary and pontine centers, seem to be concerned in the maintenance of the normal tone of the muscles concerned in defecation, though these impulses are not necessary, since the act may occur in a normal manner, unconsciously, in men and animals in whom the cord has been severed or destroyed.

VI. Descending impulses from the red nucleus and other basal ganglia may cause defecation to be affected by the emotional states. Thus defecation may be either inhibited or be performed involuntarily under emotional stress.

VII. The associations between the defecation, micturition, erection, and parturition centers are very intimate. Thus defecation may be initiated involuntarily or may be inhibited by the different states of these other centers.

The Vesico-spinal Center

Micturition is accomplished in much the same manner as defecation, and the vesico-spinal center is influenced by nerve impulses from the same sources.

The lack of control of the vesical sphincter in children and sometimes in adults may be associated with slight malpositions of the lumbar vertebræ, the sacrum, and the innominates. Certain peripheral irritations, as from worms, or from adherent prepuce or hooded clitoris, may affect the vesico-spinal center.

The Genito-spinal Center

This center has been demonstrated for male dogs and for men, but no homologous center has been demonstrated in the female. Impulses from this center act as inhibitors of other lumbar centers and of many medullary centers. The efferent impulses pass to the various centers for the skeletal muscles concerned in coition and to the erection center. The activities of the genito-spinal center are influenced by impulses from the following sources:

I. Sensory impulses from the genital tract, and to a certain extent from neighboring tissues.

II. Descending impulses from the red nucleus and neighboring basal ganglia. These impulses are concerned in the emotional states, and may be either stimulatory or inhibitory. The ill effects of the reading of erotic literature by young people may be traced in part to the impulses aroused in the emotional centers by such reading.

III. Descending impulses from the cerebrum probably act indirectly through the action of the volitional impulses upon other structures and through the influence of the descending volitional impulses upon the basal ganglia.

The Erection Center

This center lies in the lower part of the lumbar cord. It is to be considered a vaso-motor center, and it is in very close association with the genito-spinal center. Its efferent impulses pass downward for the most part to the origin of the nervi erigentes. This center is influenced with and by the genito-spinal center, but seems to be somewhat more easily affected by sensory impulses. In certain cases of malpositions of lumbar vertebræ, sacrum, coccyx and innominates the activity of the erection center may become abnormal. Whether the bony lesion is ever the only cause of these disturbances is not certainly known, but the correction of the lesions, together with the correction of whatever may be found wrong from the hygienic standpoint, is sometimes followed by very speedy and apparently permanent relief in the cases not associated with local structural causes of the disturbances or with disease of the spinal cord.

The Parturition Center

This center lies in the upper part of the lumbar cord. It seems to be concerned more with the regulation of labor than with its initiation.

The parturition center acts by sending impulses to the uterine muscle, to the dilator center for the cervix uteri, to the centers for the abdominal muscles, and to other centers in the lumbar cord. It is not certain whether the impulses affecting the action of the respiratory center are from the parturition center or from the other sources affecting the respiratory centers. The physiology of this center requires further study.

The parturition center may be affected by impulses from the following sources:

I. Sensory impulses from the uterine and neighboring

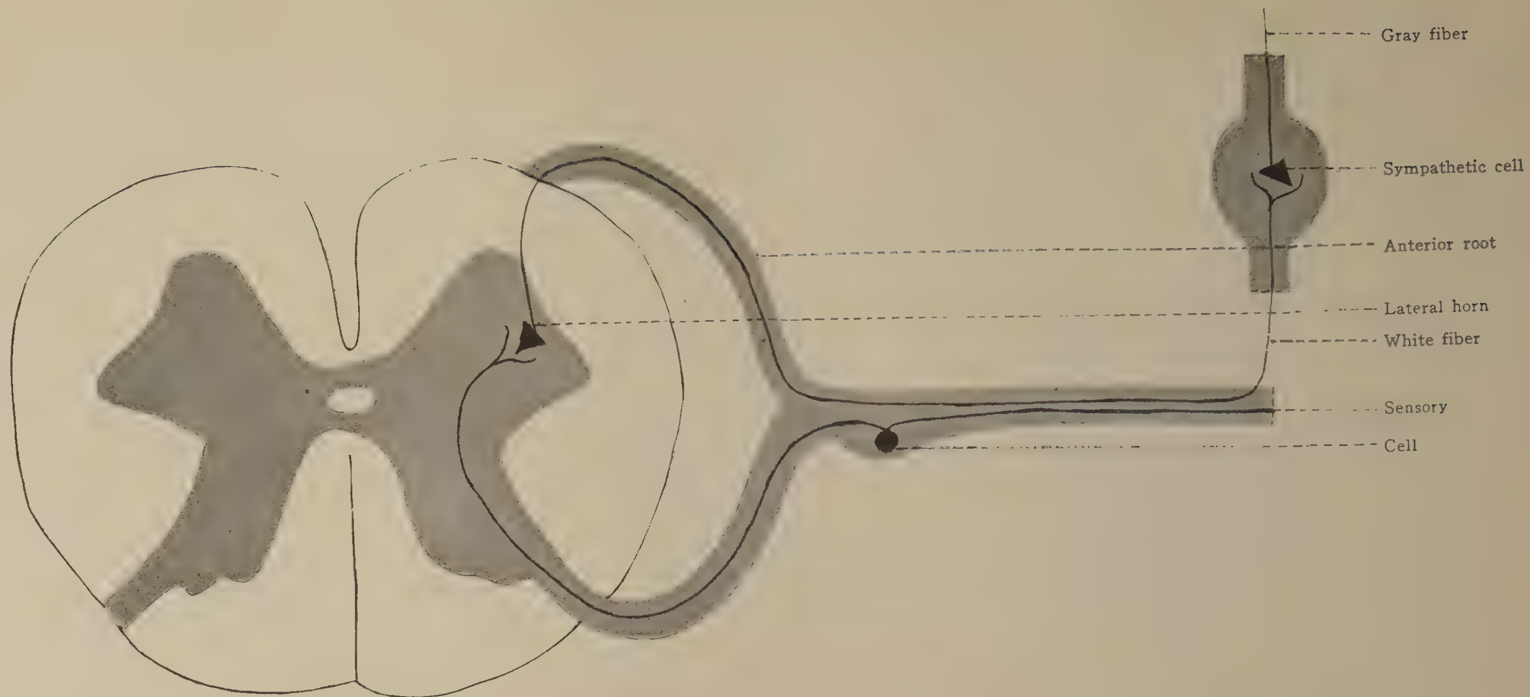


Fig. 45. Simple visceral reflex arc.

tissues may decrease the uterine contractions, but usually increase them.

II. Descending impulses from the red nucleus and related ganglia may initiate, postpone or hasten labor. This is evident in the premature births associated with battles, disasters, and other emotional storms. It seems probable that labor may be postponed by excessive disgust or fear, and the emotional states may be responsible for other variations from the normal progress of parturition.

III. Probably no direct volitional impulses affect the center, but volitional impulses may affect the abdominal muscles and the emotional centers, and thus may indirectly affect the progress of labor.

IV. Somatic sensory impulses may perhaps be concerned in influencing the action of this center. It seems more probable that the place of slight malpositions of structural tissues in modifying labor is more prominent in affecting the nutritional and developmental conditions than as a factor in labor itself. This does not apply to the gross bony malpositions which mechanically affect the birth canal.

V. There is some evidence in favor of the view that the quality of the blood flowing through the center may affect its activity.

Vaso-motor Centers for the Pelvic Organs

These have not been well demonstrated, except as already given. The lumbar cord contains the vaso-motor centers for the uterus, the urinary bladder and the prostate. These centers seem to be affected abnormally by somatic sensory impulses from the structures innervated from the same spinal segments. Congestions of these organs are frequently found associated with malpositions of the lumbar vertebræ, the innominates, and the sacrum. Experimental stimulation of the somatic tissues innervated from the same segment of the cord is found

to affect the circulation of these organs. Experimental stimulation of the visceral tissues innervated from the same segments does not produce such noteworthy effects. No explanation is offered for this phenomenon.

The Visceral Centers in the Sacral Cord

The nervus erigens passes directly to the hypogastric plexus. It terminates by entering into the formation of the pericellular baskets of the small ganglia of this plexus. The gray fibers from these small ganglia pass to the blood vessels, chiefly of the external genitals. The visceral efferent impulses of the sacral centers pass chiefly by way of these paths.

The Cervico-dilator Center

The circular fibers of the os uteri are inhibited by impulses from this center. The center seems to be affected chiefly from the parturition center in the lumbar cord. Experimental and clinical evidence seems to indicate that the activity of this center may be affected by sensory impulses from the somatic structures innervated from the same segments. Other relations of this center have not been sufficiently demonstrated.

CHAPTER XII

THE MEDULLARY AND PONTINE SOMATIC CENTERS

The medulla is a mass of nerve tissue which lies caudad to the pons and cephalad to the upper extremity of the spinal cord. It is about an inch in length and about half an inch in its antero-posterior diameter. At its lower extremity it has the transverse diameter of the spinal cord, with which it is directly continuous; this is about half an inch. At its upper extremity it has a transverse diameter of nearly an inch, as has the pons, with which it also is continuous.

Its anterior aspect presents a series of grooves and ridges, which pass from above downward. The posterior surface of the medulla forms the floor of the lower triangle of the fourth ventricle. Its anterior and lateral surfaces are broken by the roots of the cranial nerves.

The white matter of the medulla is composed of ascending, descending, transverse and antero-posterior fibers. A few tracts contain both ascending and descending fibers.

Ascending Tracts

The ascending fibers are mostly continuous with those of the cord; the descending fibers, for the most part, are continuations of the same tracts in the pons. The ascending tracts are as follows:

I. The medial fillet is composed of the axons of the cells of the nucleus gracilis and the nucleus cuneatus. These axons

pass as internal arcuate fibers anteriorly, and pass behind the olivary body. They decussate, turn forward, and pass through the substance of the medulla on their way to the optic thalamus. As they traverse the medulla and pons the axons of terminal nuclei of the sensory cranial nerves (except the auditory) are added to the fillet, and with it pass forward to the optic thalamus. This tract carries the finer sensations of touch and muscular effort.

II. The ascending anterior cerebello-spinal tract is continuous with the same tract in the cord. It passes through the medulla and pons to the region of the brachium conjunctivum, where it turns backward to enter the cerebellum. It is composed of the axons of the cells of the dorsal nucleus of the opposite side of the cord, and during its pathway through the medulla it receives axons of the terminal nuclei of the cranial nerves of the opposite side. It transmits impulses initiated by temperature changes, painful stimuli, sensations of muscular effort, and the visceral sensations. A part of the tactile impulses are carried by this tract.

III. The spino-thalamic tract is so closely associated with the tract just mentioned that it is not possible to separate them in the pons. That they are physiologically separate is certain. The fibers of the spino-thalamic tract arise from the cells of the dorsal nucleus of the opposite side, pass with the anterior ascending cerebello-spinal tract to the angle of that tract; the spino-thalamic tract then proceeds on its way to the optic thalamus. It carries the impulses of pain and temperature, but probably not of muscular effort. A part of the tactile sensations are probably carried by this tract.

IV. In the lower part of the medulla the fasciculus gracilis and the fasciculus cuneatus are found. They are the axons of the cells of the sensory ganglia, and they terminate, for the most part, in the nucleus gracilis and the nucleus cuneatus. A few fibers pass directly into the restiform body.

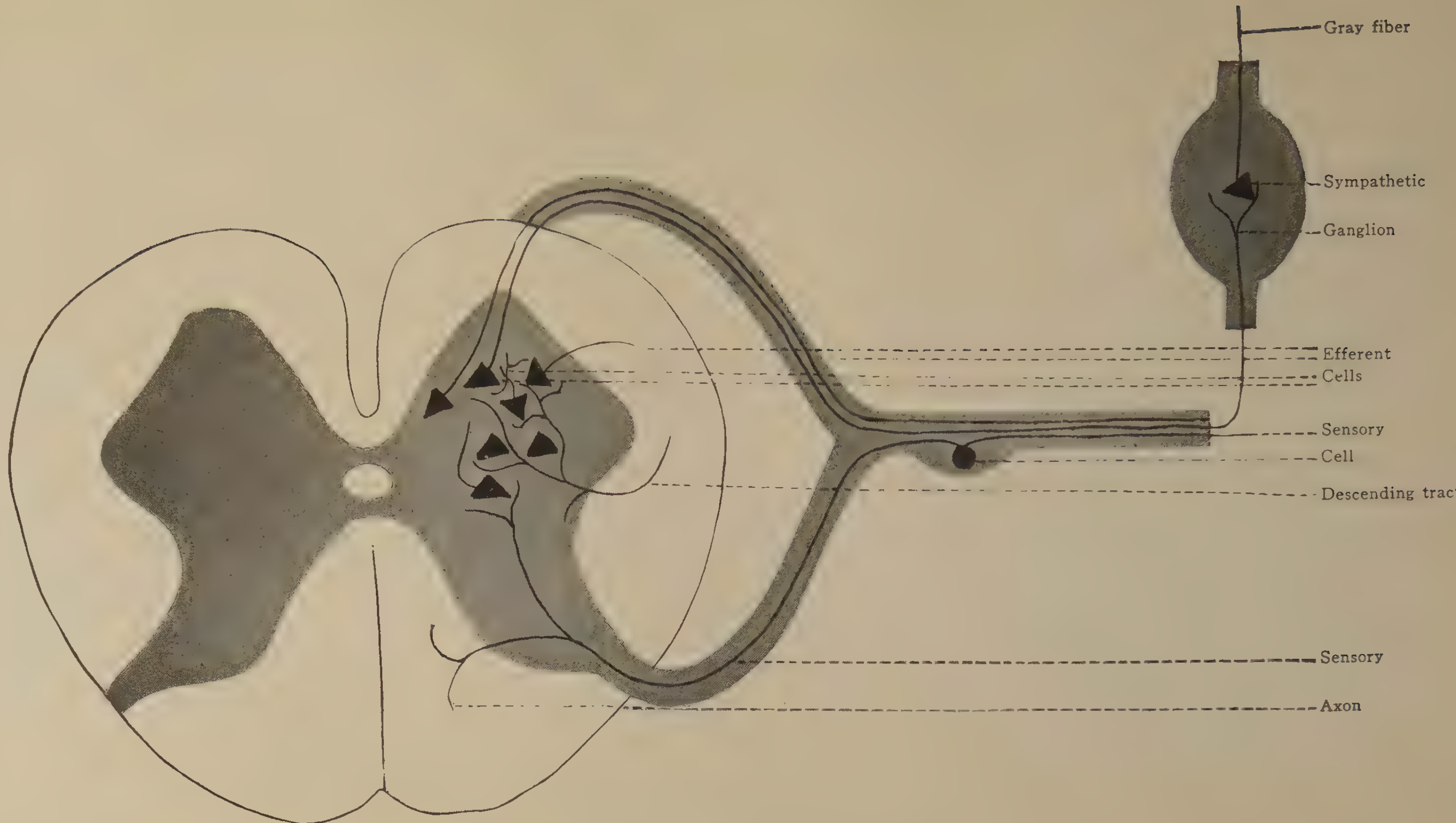


Fig. 46. Ano-spinal center.

V. In the lower part of the medulla the posterior ascending cerebello-spinal tract is found. It is composed of the axons of cells in the nucleus dorsalis, mostly of the same side, and it enters the restiform body on its way to the superior vermis. It carries visceral sensory impulses, and perhaps also impulses from other structures.

Descending Tracts

I. The pyramids occupy a prominent position in sections of the medulla. They are placed very near the anterior surface of the medulla. Near the lower extremity of the medulla about four-fifths of the fibers decussate just under the surface. The decussation is easily seen from the anterior aspect of the medulla. The other one-fifth of the pyramidal fibers remain upon the same side until they approach the segment of their termination in the cord. The fibers of the pyramidal tracts are the axons of large pyramidal cells of the precentral convolutions of the cerebral cortex of the same side (before the decussation). They are distributed to the central gray matter of the crescent of the opposite side of the cord, and to the motor nuclei of the cranial nerves of the opposite side.

II. The anterior longitudinal bundle (tecto-spinal tract) is continuous with the same tract in the pons and in the cord. It is composed of axons of the cells of the colliculus. It terminates in the center of the crescent of the spinal cord. Many of its fibers terminate in the cilio-spinal center in the upper part of the thoracic cord. It carries the impulses concerned in the reflex actions initiated by visual impulses, and perhaps other sensory impulses.

III. The rubro-spinal tract is continuous with the same tract in the pons and in the spinal cord. It is composed of the axons of the cells of the red nucleus and probably of neighboring gray matter, and it terminates in the center of

the crescent of the spinal cord, and in the nuclei of the cranial motor nerves.

IV. The spinal tract of the trigeminal nerve is composed of the descending limb of the T-shaped division of the entering trigeminal sensory roots. The axons are in the semilunar ganglion (Gasserian ganglion). The fibers terminate in the substantia gelatinosa of the posterior horn of the cord of the upper cervical segments, and in the nucleus of termination of the fifth nerve in the medulla.

V. The tractus solitarius is a bundle of fibers composed of descending fibers from the sensory part of the seventh, ninth and tenth cranial nerves. It passes to the centers of the lower medulla and upper cervical cord, and is supposed to be concerned in carrying the impulses of the respiratory reflexes.

Mixed Tracts

I. The medial (posterior) longitudinal bundle is continuous with the anterior fasciculus proprius of the cord. Through this tract the axons of cells in lower nuclei pass to enter into higher nuclei, and axons of cells in higher nuclei pass toward cells of the lower nuclei. Thus these fibers are associational in function. Part of the ascending fibers of this tract in the cord are joined by other fibers from the sensory nuclei of the cranial nerves, and of these some terminate in other nuclei of the sensory and motor cranial nerves, while others pass to the optic thalamus.

The descending part of the medial longitudinal bundle is composed of the ponto-spinal tracts. These are axons of cells of the reticulum of the pons, and they terminate by forming synapses with the cells of cranial motor nerves and the anterior horns of the cord. Part of the ponto-spinal fibers are crossed, part are not crossed.

II. The lateral fasciculus proprius is made up of ascending and descending fibers, which bring the different levels of

the medulla into functional relationship. Among these fibers lies the descending olivary bundle, which is supposed to carry impulses from the centers of the pons and the basal ganglia to the olive, and the olivo-spinal tract, which is supposed to carry impulses from the olive to the spinal centers.

III. The restiform body contains a number of ascending and descending fibers. These are:

(*a*) The cerebello-spinal ascending and descending fibers; (*b*) the external arcuate fibers, which pass from the nucleus gracilis and nucleus cuneatus of the opposite side, chiefly; (*c*) fibers from the inferior olive to the cerebellum and from the cerebellum to the inferior olive.

Horizontal Fibers

The transverse and antero-posterior fibers may be grouped for convenience in description.

I. The axons of the nucleus gracilis and nucleus cuneatus pass as anterior and posterior external arcuate fibers toward the anterior part of the medulla. The posterior set surround the olive of the same side, pass to the opposite side, and enter the restiform body. The anterior set pass between the olives, surround the olive of the opposite side, and enter the restiform body. Both sets of external arcuate fibers give off some fibers to the olives and the arcuate nuclei both of the same and the opposite sides.

The decussation of the fillet causes these fibers to appear as horizontal fibers.

II. In their decussation the pyramidal fibers pass transversely for a short distance.

III. The medullary striæ are axons of the cells of the auditory nuclei. They pass from these nuclei, placed far laterally as they are, toward the median raphe. Here they plunge into the substance of the medulla and form synapses with the cells of the various secondary auditory nuclei.

IV. The root bundles of the vestibular, hypoglossal, glosso-pharyngeal, vagus and spinal accessory nerves are seen as antero-posterior fibers.

V. Various small bundles of horizontal fibers connect the nuclei of each level in functional relationship. This connection varies according to the physiological requirements of the different nuclei.

Centers of the Medulla

The centers for the trigeminal, facial, acustic, glosso-pharyngeal, vagus, accessory and hypoglossal nerves are found in part or completely in the medulla. These centers are discussed elsewhere, and will not be considered at this time.

The Arcuate Nucleus

This group of nerve cells lies upon the anterior aspect of the medulla. It is continuous with the nucleus pontis, with which it is probably homologous. Some of the external arcuate fibers form synapses with the cells of this nucleus, and it seems probable that other fibers from the medullary nuclei may also terminate in this nucleus. This relation is not certainly known, but in sections a number of fibers apparently from the nucleus of the trigeminal and from unidentified cell groups of the medulla seem to enter the arcuate nuclei. (Fig. 48.)

The Inferior Olive

This structure is found as such in mammals only. Masses of nerve cells of similar arrangement and position are found in lower vertebrates, even among fishes. By some authors these centers are held to be homologous with the olive of the higher vertebrates. (Figs. 49, 50.) The statement frequently

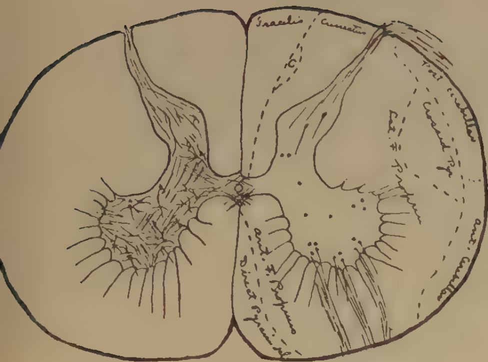


Fig. 47. Diagram of spinal tracts. Section of spinal cord of ox. 5 diameters.

Fig. 49. Section through medulla of human embryo, 5 months. The olivary body occupies the anterior area. The cells are shown of larger size than is evident in the section with this magnification, about 10 diameters.

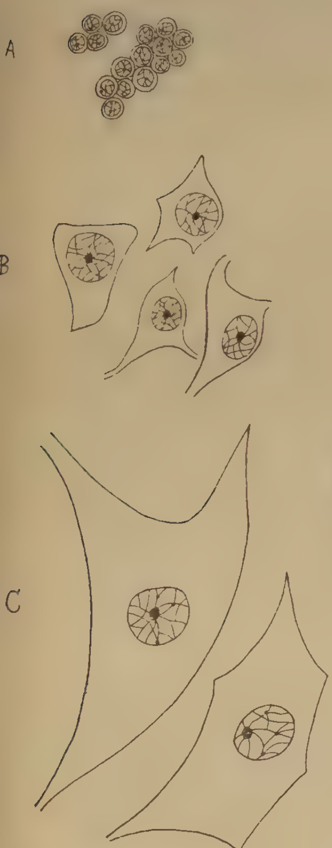


Fig. 48. Groups of nerve cells from homologous centers in human medulla, showing increase in size of cell bodies. A—10 weeks' embryo. B—5 months' embryo. C—Adult woman. All three magnified 800 diameters.

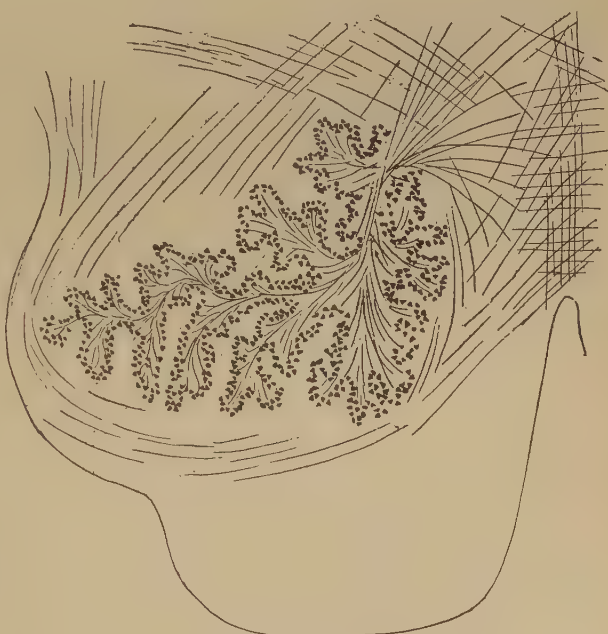


Fig. 50. Section through olivary body of adult woman. 10 diameters.

made that the olivary nucleus does not appear until the sixth month of embryonic life does not seem true. (In a fetus of five months supposed existence I have found the olivary nucleus fairly well developed.)

Two accessory olivary bodies are found.

The olive has functions similar to those of the cerebellum, with which it is very closely related in structure.

Lesions of the olive are associated with loss of coördination, ataxia of the cerebellar type, usually nausea, and other symptoms of cerebellar disease. Antemortem diagnosis of olivary disease is probably impossible, in the absence of symptoms indicative of localization of surrounding structures.

Fibers enter the olivary nucleus from the following sources:

I. Axons of the nucleus gracilis and the nucleus cuneatus enter the olivary nuclei of both sides. Probably other secondary sensory axons also enter the body.

II. Fibers from the cerebellar hemispheres pass by way of the restiform body to the contra-lateral olive.

III. Descending fibers, probably from the lentiform nucleus, terminate in the olive.

Fibers leaving the olivary nucleus pass to the cerebellum, either to the nucleus dentatus or to the hemispheres, chiefly of the opposite side. Other fibers from the olivary nucleus pass downward through the cord to enter into gray matter of the various levels through its whole extent.

Gracilis and Cuneatus

These nuclei may be considered as one. Indeed, the gray matter of which they are composed is continuous. They differ only in the fact that the cuneatus receives the sensory impulses from the upper part of the body, while the gracilis receives the impulses from the lower part of the body. Their central connections are similar.

Fig. 51. Cross section through medulla of 5-day kitten. Semidiagrammatic. The V-shaped floor of the fourth ventricle is placed uppermost. At the lateral angles are seen the cells of the nucleus cuneatus. Axons of these cells pass anteriorly and decussate, then turn forward as the median fillet. Other fibers pass further ventrally and enter the olivary body. At the ventral surface is seen the arcuate nucleus. 10 diameters.

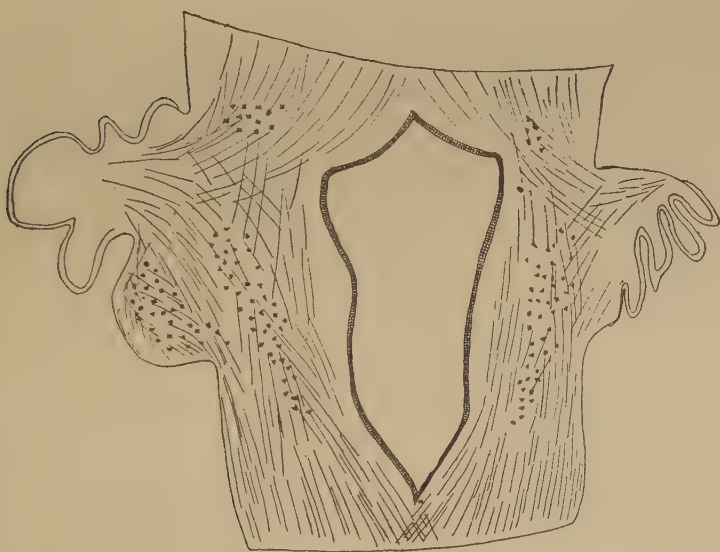


Fig. 52. Coronary section through medulla and restiform body of 4-day kitten. The fourth ventricle occupies the central part of the cut. It is lined with ependyma. The cells of the nucleus gracilis lie on either side. The vestibular nucleus is shown on one side. The folds of the cerebellum are indicated.

These nuclei receive the ascending fibers which are the axons of cells of the sensory ganglion on the posterior roots of the cord, and of cells in the posterior horns of the cord with which the entering axons form synapses. The impulses thus transmitted are concerned in the sensations of touch and muscular effort, especially such of these sensations as are concerned in delicate perceptions, in exact localizations, and which are speedily recognized.

The axons of these nuclei have the following destinations:

I. As internal arcuate fibers the axons pass through the medulla, decussate, and turn forward as the medial fillet. This is the most direct path of the sensory impulses to the centers concerned in consciousness. The fillet terminates in the optic thalamus, after giving fibers to the cranial nerve nuclei and the colliculi.

II. Axons pass as external arcuate fibers, both anterior and posterior, around the olives and into the cerebellum by way of the restiform body. From these tracts fibers are given off to the olives and to the arcuate nuclei. (Fig. 51.)

III. Axons pass into the restiform body and the cerebellum directly. (Fig. 52.)

IV. Axons pass anteriorly to the nuclei of the cranial nerves.

Inferior Lateral Nucleus

This nucleus is homologous with the nuclei of the pontine reticulum. It receives fibers from the anterior ascending cerebellar tract, the nucleus gracilis and the nucleus cuneatus, and probably also from the terminal nuclei of the cranial sensory nerves and from the corpora mammillaria. Its axons pass into the cerebrum by way of the brachium conjunctivum, and to the spinal cord with the ponto-spinal fibers in the anterior longitudinal bundle.

The Pons

The pons is a structure of irregularly cylindrical outline. It is about an inch long, a little more than an inch broad, and about an inch in its antero-posterior diameter.

Laterally, the transverse fibers which appear upon the surface of the pons gather together and form the brachium pontis, or middle cerebellar peduncle. Its anterior aspect presents only a mass of transverse fibers. Its posterior aspect forms the floor of the upper triangle of the fourth ventricle. Its superior boundary is continuous with the midbrain, its inferior with the medulla.

The Pontine Tracts

The pons is composed of a very complex network of fibers and groups of nerve cells. The bundles of fibers are variously separated and combined, so that it is not easy to trace even the well-recognized tracts through the rete mirabile. The fibers which enter into the formation of this complex network are as follows:

Descending Tracts

I. The pyramidal tracts descend through the anterior portion of the pons. These fibers are the axons of the neurons of the central gyri, and are on their way to the spinal and medullary centers. The decussation of these fibers occurs in the medulla, it will be remembered, so that injuries to the pyramidal tracts in this location produce the symptoms peculiar to lesions of the cortex or capsule, so far as the character of the paralysis is concerned.

II. The tecto-spinal fibers pass through the pons on their way from the quadrigeminate bodies to the spinal and medullary centers.

III. The rubro-spinal fibers pass through the pons on their way from the red nucleus, and probably also from the substantia nigra and the sub-thalamic region, to the spinal and medullary centers.

All of these descending tracts send terminals and collaterals to the pontine centers. By means of this connection the coördination of the lower centers is maintained, in part, and also the action of the sixth and fifth nerve nuclei are controlled.

IV. Fibers from the red nucleus and other structures related to it in function send many fibers to the nucleus pontis, and thus enter into relationship with the cerebellum.

V. Fibers from the temporal, occipital and frontal lobes of the cerebrum send fibers to the pontine nuclei, and thus enter into relationship with both the cerebellum and the lower spinal medullary centers.

Ascending Tracts

I. The median fillet passes near the posterior surface of the pons, near its lateral aspect. It is composed of the axons from cells in the nucleus gracilis, nucleus cuneatus, and the terminal nuclei of the sensory cranial nerves as they pass to the optic thalamus. It will be remembered that this tract gives off fibers also to the quadrigeminates and perhaps to other neighboring nuclei.

II. The lateral fillet lies lateral and posterior to the median fillet. It is composed of axons of the cells of the auditory nuclei, and also a few fibers directly from the vestibular and cochlear ganglia. The cells of the nucleus of the trapezoid body send fibers to the lateral fillet. The fibers of the trapezoid body pass into the lateral fillet also. The lateral fillet passes upward through the pons to the optic thalamus, and sends many fibers to the posterior colliculus.

III. The anterior ascending cerebello-spinal fasciculus

passes through the pons on its way to the cerebellum. This tract arises from the cells of the dorsal nucleus (Clarke's column) in the cord, runs through the neural axis to the neighborhood of the brachium conjunctivum, turns backward, and enters the cerebellum to terminate in the cortex of the superior vermis. As this tract passes through the pons it gives off a bundle of fibers with which it has been very closely intermingled in its entire previous course. This bundle, the spino-thalamic tract, is not to be distinguished from the anterior ascending cerebello-spinal tract until their division in the region of the brachium conjunctivum; but the fact that it is physiologically a distinct tract is shown by the effects of lesions involving the two divisions; the spino-thalamic tract evidently carries impulses of pain and temperature exclusively, and the tactile sense, in part; the anterior ascending cerebello-spinal carries impulses of muscular sense, chiefly.

Mixed Tracts

I. The posterior or medial longitudinal bundle lies near the posterior part of the medial raphe. It includes both ascending and descending fibers, which carry impulses from the various nuclei of the cranial nerves and their related nuclei to other cranial nerve nuclei.

II. The anterior longitudinal bundle is physiologically homologous with that just mentioned. It carries the fibers which transmit the impulses from the different centers concerned in the movements of the eyeball to other centers having the same or related functions. The tecto-spinal tract is carried with it.

III. Unidentified fiber groups may be concerned in transmitting impulses upward and downward to and from the various nuclei and centers in the pons, and both above and below the pons.

Transverse Tracts

I. The ventral portion of the pons is occupied by large masses of fibers, which pass transversely across and through the structure. These are of two classes. The axons of cells in the cerebellum, chiefly the Purkinje cells of the lateral hemispheres, but probably partly the cells of the dentate nucleus, form synapses with the cells of the pontine nuclei, chiefly of the opposite side, but partly of the same side. Axons of the cells of the pontine nuclei pass to the cerebellar hemispheres, chiefly of the opposite side, but partly of the same side.

II. The fibers of the corpus trapezoideum are a conspicuous feature of pontine sections. The fibers of this body arise from the different auditory nuclei and pass to the opposite side of the pons. They turn abruptly forward and form the lateral fillet. About midway from the raphe to the angle the nucleus of the trapezoid body is interposed, and in this body, and in the superior olive and its accessory nuclei, the fibers are interrupted. The axons of the cells of these bodies assist in the formation of the lateral fillet.

III. A number of fibers pass from the nuclei of either side of the pons to form synapses with symmetrical or related nuclei of the opposite side.

Antero-posterior Bundles

The antero-posterior bundles of the pons include those fibers which associate the different nuclei, those collaterals and terminals from the ascending and descending tracts which enter or leave the nuclei placed anteriorly or posteriorly to them, and the efferent fibers of the motor nerves as they seek their places of emergence from the surfaces.

Pontine Centers

The term nucleus pontis is used to include the masses of cells scattered through the ventral part of the pons. It is

considered as a single nucleus, on each side, whose cells have been separated by the transverse fibers of the pons and by the descending bundles of the pyramidal, fronto-pontal, temporo-pontal and intermediate tracts.

The cells of this nucleus are large multipolar cells, surrounded by the interlacing fibrillæ of the incoming axons, which thus form synapses with them.

These incoming fibers include the axons of cells in the frontal and temporal lobes of the cerebral cortex, and probably from other cortical areas, and from the basal ganglia. The pyramidal tracts give off collaterals and terminals to the nucleus pontis also.

The axons of the nucleus pontis pass for the most part to the contra-lateral cerebellar hemisphere. A few pass to the cerebellar hemisphere of the same side.

Reticular Nuclei of the Pons

In the reticular formation of the pons are found small scattered groups of cells. These have been called, from their position, lateral median, superior central, median central, and inferior central. The cells of these nuclei are large and multipolar, and their bodies and dendrites are surrounded by the branching fibrillæ of the incoming fibers. The axons of these cells bifurcate into an ascending and a descending branch. The destination of the ascending branches is not known. The descending branches pass downward through the pons, medulla and spinal cord. They terminate at different levels in these structures by forming synapses with the cells of the motor nerve nuclei to the lowermost spinal centers. These ponto-spinal tracts undergo partial decussation in the medulla.

The Trapezoid Nucleus

The nucleus of the trapezoid body includes a number of scattered cell groups within the trapezoid fibers. The fibers

of the trapezoid body and medullary striæ, axons of the auditory nuclei, form synapses with the small multipolar cells of this nucleus. The axons of the cells of the nucleus pass with the uninterrupted fibers from the auditory nuclei to form the lateral fillet. The axons from the auditory nuclei terminate by forming a cuplike expansion upon the bodies of the cells of the trapezoid nucleus. This form of synapsis is not described for other centers.

The sensory nuclei of the trigeminal and auditory nerves are found in part within the pons. The motor part of the trigeminal and the facial, and the nuclei of the trochlear, abducens and a part of the oculo-motor nerves, are also found within the pons. The description of these centers is given in connection with the discussion of the relations of the cranial nerves.

The Superior Olivary Nuclei

The olivary group of nuclei includes the superior olive, the semilunar nucleus, and the preolivary nucleus. These cell groups contain small multipolar nerve cells. They receive axons from the auditory nuclei of both sides and send axons into the lateral fillet. They send axons also to the nuclei of the abducens, trochlear and oculo-motor nerves. Thus the nuclei form a part of the auditory-ocular reflex arc. The movements of the eyeballs in answer to sudden sounds are in part mediated by way of this pathway.

Functions of Pons

The functions of the pons are thus seen to be largely in the nature of correlation. The pons forms part of the pathway to and from the cord, cerebrum and cerebellum. It is chiefly functional in the transmission, but certain of the coördinations and the reflexes are mediated within its gray matter.

Diseases of the pons are rare, and are not apt to be recognized antemortem. The injury of any perceptible area of the pons is associated with immediate death; the injury of the cranial nerve nuclei is associated with the symptoms referable to the loss of function of these nerves. The injury to the pontine nucleus may be associated with incoördination of movements, or, if the lesion be gradually produced, no localizing symptoms may be found. Injuries of the ascending or descending tracts produce the symptoms due to the loss of the corresponding functions.

CHAPTER XIII

MEDULLARY AND PONTINE VISCERO-MOTOR CENTERS

In the gray matter of the medulla and pons lie a number of cell groups which may or may not be identical with the centers of the cranial nerves, but which certainly are concerned in the coördination of the nerve impulses which control the organs and systems of organs of certain functions and functional relationships. These cell groups are called centers, not because it is certainly proved that they have in all cases an actual, individual cell grouping, but because they have the functional value of specific cell groups. In other words, any one of these higher viscero-motor "centers" may be formed by a certain and exact group of nerve cells, whose location has not yet been demonstrated, or it may be merely a certain synaptic relationship between the centers of the different cranial nerves, or of the centers to which these are closely related. In the former case, the localization of these centers is merely a matter of further study; in the latter case, localization is impossible, since the same nerve cells, through variations in the physiological conditions of their associated neurons, might be concerned in coördinating different and even antagonistic functions. These matters are to be determined by further study.

For the present we only know that in the medulla and pons somewhere within certain circumscribed limits lie cells

or cell groups whose activity does secure the coördinate physiological activity of organs or related groups of organs in the performance of certain duties, and that this coördination is effected by means of sensory impulses, associational impulses among the centers, and the descending impulses from the midbrain, basal ganglia and cerebral cortex.

The Vaso-constrictor Center

This center is concerned in the regulation of the circulation of the blood. It controls the changes in general blood pressure as well as the circulation through specific organs.

This center lies near the nucleus of the facial nerve and near the superior olivary nucleus. It begins just caudad to the inferior colliculus and extends downward into the medulla, either as an individual center or through its related nerve cell groups. The center itself is supposed to be about one-tenth of an inch in length, but section of the medulla elsewhere may produce something of the effects of section of the area of the center itself. The center is bilateral, and its two halves are so thoroughly associated in function that under normal conditions the circulation of the blood in the two halves of the body is maintained in a symmetrical manner. The center is one of those whose action is constant — that is, it is in a condition of constant tone. This constant activity is due in part and perhaps altogether to the fact that it is subject to the constant stimulation of the nerve impulses reaching it.

The vaso-constrictor center is known to vary in activity according to the stimuli reaching it from a number of different sources. It may be concluded, therefore, that the axons of the nerve cells of the different structures whose stimulation forms an efficient stimulus for the vaso-motor center reach that center in order to perform these duties. It is not known whether these impulses are carried to the vaso-motor center by the axons of the sensory neurons of the first, second or

higher orders; it is only known that sensory impulses do affect the activity of this center.

The vaso-constrictor center receives impulses which may either increase or decrease its activity. It is evident that in the absence of any tonic activity no conceivable nervous impulse could cause a decrease in its activity. The recognized sources of these impulses are as follows:

I. Descending impulses from the basal ganglia affect the action of the vaso-constrictor center both in increasing and in decreasing its activity. In the emotional states, such as shame, pleasure and some forms of anger, in certain instinctive reactions, as sex excitement, and some other conditions, the splanchnic vessels are constricted and the skin arterioles are dilated, so that a reddening of the face or of the whole body occurs. Under other emotional states, such as fear, some forms of anger, horror, and in the presence of great excitement, the peripheral arterioles are constricted and the splanchnic vessels dilated. Thus the pallor is caused which is found in these conditions. There is some reason to believe that some at least of these reactions are of functional value in preserving the lives of the individual or his kind; thus, the accumulation of the blood in the central organs may be valuable in preventing the hemorrhages which are likely to follow the attack whose imminence produced the fear. The further discussion of this matter belongs to the consideration of the basal ganglia and their relations. The effects of the emotional and instinctive reactions upon the vaso-constrictor center must be recognized.

II. Impulses from the heart itself may affect the action of the vaso-constrictor center by either increasing or decreasing its activity. The vagus carries a small bundle of fibers called the depressor nerve. Since this nerve is carried in a separate bundle in certain mammals, its individuality is unquestioned. Impulses carried by this nerve seem to be initiated by

the pressure of the blood within the heart, or by the pressure of the contracting heart muscle upon its sensory nerve endings. This pressure, itself a source of embarrassment to the heart's action, becomes the initial cause of the nerve impulses which lead to relief. For the impulses carried to the medulla by the depressor nerve act upon the cells of the vaso-constrictor center in such a way as to lessen the activity of that center, lower the blood pressure, and thus secure the relief of the heart.

Pressor fibers are found in the sensory nerves of the heart also. These impulses are probably aroused by the condition of the muscle fiber in the diminution of its nutrition. When the pressure of the blood in the aorta, and thus in the coronary arteries, becomes low, the heart muscle is poorly nourished and the pressor nerve is stimulated. The action of the cardiac pressor nerve causes increased activity of the vaso-constrictor center and an increase of arterial pressure.

III. Sensory impulses from any of the somatic structures of the body may affect the action of the vaso-constrictor center. Stimulation of the central end of the divided great sciatica nerve causes rise of blood pressure. Stimulation of the central end of any large nerve trunk has the same effect, usually. Severe pain in any part of the body causes vaso-constriction, not only in the painful area, but in the general arterial system.

IV. Association neurons connect this center with the heart, respiratory and other centers of related function.

V. Sensory impulses from viscera affect the vaso-constrictor center either by increasing or decreasing its tonic activity. The stimulation of the sensory nerves of the abdomen in surgical operations, the stimulation of the sensory nerves of the urethra in passing a sound, or of the cervix uteri or of the anal tissues in dilatation, may cause so profound a lowering of the blood pressure as to result in shock

or in syncope. Stimulation of these areas may cause first a sudden increase of blood pressure, followed by the fall, or the lowering may not be preceded by any perceptible rise, or, in the case of less ferocious stimulation, the rise of blood pressure may not be followed by any noticeable fall.

The activity of the vaso-constrictor center seems to be affected also by the presence of certain substances in the blood stream. These include the products of muscular fatigue, though not necessarily the excess of carbon dioxide or the lack of oxygen. The presence of small quantities of various acids in the blood causes a fall of blood pressure, evidently due to a partial paralysis of the vaso-constrictor center. Certain drugs seem to have a selective action upon this center also. The fact that the fatigue products lessen the activity of the center, as well as the presence of small amounts of acid, may account for the lowering of the blood pressure in neurasthenics, as well as in the normal degrees of fatigue.

The action of the vaso-constrictor center is thus seen to depend upon a number of more or less antagonistic factors. The physiological conditions of its intrinsic neurons must affect the nature of the reaction, since the cells are probably not different from the other nerve cells in their physiological activities. The nature of the impulses sent out from the center at any given time must, then, depend upon the condition of the cells of the center at that time, the character of the blood flowing through it, and the algebraic sum of the stimulating and inhibiting impulses reaching it at that time.

The impulses initiated by the activities of the vaso-constrictor center are carried as follows:

Descending impulses are carried, probably in the anterior longitudinal bundle or in the anterior fasciculus proprius, to the levels of the spinal cord, including the first or second thoracic to the second or third lumbar segments. In these levels the descending fibers terminate by entering the gray

matter of the lateral horn, and forming synapses with the cells therein. The axons of the cells of the lateral horns (lower vaso-constrictor centers) leave the cord, mostly by way of the anterior roots, but partly by way of the posterior roots, and enter into the formation of the white rami communicantes. These fibers enter the sympathetic chain, pass through one or more ganglia, and terminate by entering into the formation of the sympathetic pericellular network. The gray axons of the sympathetic cell pass without interruption to the walls of the blood vessels. The chief innervation is to the walls of the arterioles, but the muscle fibers of the larger arteries and the veins also receive nerve fibers.

Vaso-dilator Nerves

It has been supposed that, since the existence of the vaso-constrictor center is so certainly demonstrated, a vaso-dilator center should be found in the same region. No evidence of a dilator center has been found, though dilator nerves are recognized. The physiology of dilator nerve impulses remains to be worked out by experimental methods.

Dilator fibers have been shown to exist in the following regions:

I. The facial nerve carries dilator fibers for the submaxillary and sublingual glands by way of the chorda tympani.

II. The glosso-pharyngeal nerve carries dilator fibers for the tongue and pharynx, and by Jacobson's nerve for the parotid gland.

III. Dilator fibers are carried in the splanchnics.

IV. Dilator fibers are carried in the sympathetic chain. It is not known whether these are transmitted through sympathetic neurons, or whether the fibers are simply carried with the sympathetic fibers.

V. The nervi erigentes carries dilator fibers to the erectile tissues of the genitalia.

The Respiratory Center

This center lies very close to the vagus center; it may be identical with it, or it may coincide with the nucleus of the tractus solitarius, or it may be composed of other cell groups in this neighborhood. It is known to be placed in the gray matter of the medulla near the tip of the calamus scriptorius, and to extend through an area of about a quarter of an inch.

The center is bilateral, but the two halves are closely related by associational fibers. If medial section is made, the two halves act synchronously so long as the conditions remain normal, or approximately so; but when the movements of either side of the thorax are interfered with, the action of the two sides may become unsymmetrical.

It is supposed that an inspiratory center exists, and an expiratory center, and these act independently, but harmoniously.

The action of the respiratory center depends largely upon the character of the blood circulating through it. A lack of oxygen causes increased respiratory movements, but an even smaller increase in carbon dioxide causes greater increase in the movements. Acids or the fatigue products, or the products of bacterial action, may increase the activity of this center.

Nerve impulses affecting the center are carried to it as follows:

I. Descending impulses from the cerebral cortex bring the respiratory movements under a certain amount of volitional control. This control is bilateral. The respiratory muscles are not usually disturbed in paralysis.

II. Descending impulses from the basal ganglia cause the respiratory movements to be affected by the emotional and instinctive activities.

III. Probably impulses from the cerebellum are concerned in securing coördination of the respiratory muscles, in

part, though the respiratory movements are rarely disturbed in cerebellar disease.

IV. The vagus carries sensory fibers of two classes which act upon the respiratory center. One class of sensory impulses arises from the pressure conditions in the lungs at the end of inspiration; these impulses either inhibit the action of the inspiratory center or stimulate the expiratory center. Since the act of expiration seems almost or quite purely passive, it seems that the first must be the ordinary relationship. The other class of nerve fibers carries the impulses initiated by the pressure conditions at the end of expiration. These impulses stimulate the inspiratory center.

V. Stimulation of the superior laryngeal nerves initiates expiratory movements only. The irritation of the laryngeal membrane under ordinary conditions causes a cough. This respiratory act is modified by the simultaneous occurrence of the reflex actions of the glottis and the respiratory movements of forced expiration. A separate center for coughing is recognized.

VI. Stimulation of the glosso-pharyngeal nerve, either at its center, its root, or the area of its distribution, causes the inhibition of the respiratory movements. The value of this reaction is apparent in the swallowing reflex.

VII. Stimulation of the area of distribution of the trigeminal nerve may be followed by the sneeze. The physiological action of the pathway of this reflex is not exactly known.

VIII. Stimulation of the sensory endings in the skin stimulate inspiration. Excessive stimulation of the skin areas may cause painful forced contractions of the inspiratory muscles, with partial suspension of the respiratory movements. The occurrence of syncope in such cases permits the return of the normal respiratory movements.

IX. Stimulation of the splanchnics or the abdominal

vagus causes forced expiration. This may be so forcefully produced as to cause death.

X. The respiratory center is closely related to other medullary and pontine centers by association neurons. For example, dilatation of the anus affects respiration forcibly. The impulses are carried by the fasciculus gracilis to the nucleus gracilis, and thus to the respiratory center.

The impulses from the respiratory center are carried downward through the cord by the fasciculi proprii or by the anterior longitudinal bundle to the centers of origin of the phrenic, intercostal and other respiratory muscles, and to the centers of origin of the facial, vagus and accessory nerves.

The activity of the respiratory center at any given time is determined by the pressure of the blood flowing through it, by the quality of the blood, and by the algebraic sum of the nerve impulses reaching it from the brain, basal ganglia, associated medullary and pontine centers, and the sensory nerves of the body.

The Cough Center

Closely related to the respiratory center, though probably quite distinct from it, is a cough center. Direct irritation of the area just above that given as the respiratory center may produce the act of coughing. It receives sensory impulses chiefly from the laryngeal nerves and those of the bronchi, but any branches of the vagus may sometimes be associated with coughing. Irritation of the pleura itself rarely produces cough, unless the liminal value of the cough center is abnormally low. Rarely a persistent cough may be caused by irritation of the auricular branch of the vagus.

Abnormally, the cough center may be brought into a condition of excessive irritability through its repeated action. As is the case with all nerve cells, the stimulation of the cells of the cough center lowers their liminal value. Thus, after an attack of any bronchial irritation associated with coughing, the lowering of the liminal value of the neurons concerned in

the action may be so pronounced that even after the irritation has disappeared the cough may continue; that is, the neurons are so irritable that the stimuli which are normally brought to the medullary centers initiate the act of coughing. This cough is itself a source of further irritation to the bronchial passages, and there is some tendency for the habit to be perpetuated indefinitely. In persons who are in good health, energetic, with normal habits of living, the habit soon disappears.

In caring for people in whom there is reason to believe that the cough is a symptom of the persistence of a habit it is necessary to raise the liminal value of the neurons concerned. This must be planned with regard to the condition of the patient. The person with courage and persistence may simply be told to urgently endeavor to prevent the cough. The descending inhibitory impulses from the cortical centers is sufficient to decrease the reaction, give the neurons rest, and permit the normal metabolism to be reëstablished. In other cases other methods are needed, but all must depend primarily upon securing the rest of the neurons concerned in the coughing reflex, and thus the return of their physiological activities to the normal condition.

The Heart Centers

The centers for the control of the rate of the heart's beat are placed in the medulla, with certain subsidiary centers in the cord.

The cardio-inhibitory center is either identical with or very closely associated with the glosso-pharyngeal vago-accessory center in the lower part of the lateral area of the medulla. The stimulation of this location causes a slowing of the pulse rate, but not a decrease of the amount of work done by the heart in any given time. The fibers from this center leave the cord by way of the accessory fibers, but they join the vagus almost immediately. They pass with the other vagus fibers to the cardiac plexus, where they terminate by forming

synapses with the cells of the cardiac ganglia. The stimulation of the vagus nerve gives variable results, according to the location of the point of stimulation. Stimulation of the nerve trunk before the sympathetic fibers from the upper, middle or lower cervical sympathetic ganglion reaches it causes inhibition of the heart. Stimulation of the trunk below the juncture of the sympathetic fibers with the vagus may give acceleration and augmentation of the heart's beat.

The evidence in favor of a cardio-accelerator center in the medulla is not so conclusive. Such a center must act through the intermediation of the accelerator-augmentor center in the upper thoracic cord. Certainly there is very intimate relationship between the inhibitor center and the accelerator, whether this is secured through the activity of a superior accelerator center or not.

Whether the existence of the medullary accelerator center is granted or not, the cardiac centers in the medulla must be considered as exerting the superior control. The cardiac centers are affected by impulses from the following sources:

I. Impulses from the heart itself, by way of the sensory fibers of the vagus, may lessen the frequency of the heart's beat.

II. Impulses from the basal ganglia may either increase or decrease the pulse rate and the force of the individual beats. This reaction probably depends in part upon simultaneous activity of the vaso-motor centers.

III. Sensory impulses from the nucleus gracilis, nucleus cuneatus and the nuclei of termination of the cranial sensory nerves may affect the heart's action. The impulses from the sensory fibers of the sacral and lower lumbar nerves and from the abdominal viscera seem to be especially efficient in arousing cardiac disturbances.

IV. The impulses from other centers of related function affect the cardiac centers. Thus the changes in heart beat

during swallowing, respiratory changes, vomiting, etc., are secured.

The impulses from the cardiac centers are carried to the following destinations:

I. From the medullary centers to the spinal cardio-accelerator center in the upper thoracic cord.

II. From both centers to other medullary and pontine centers of related function.

III. From the inhibitor center to the intrinsic cardiac ganglia. Three of these are recognized in the frog — von Bezold's, Remak's and Bidder's. These seem to be represented in higher animals and mammals by a rather variable number of ganglia, placed, in general, at the roots of the great veins, in the auricular septum, and at the auriculo-ventricular junction. Smaller ganglia are scattered through the heart muscle. It is not known whether the inhibitor fibers terminate in these ganglia by forming synapses with the solitary cells of the cardiac muscle, or by inhibiting the activities of the accelerator fibers in their synaptic relations in the ganglia.

The cardiac nerves in general seem to act rather by regulating the rhythm of the heart in accordance with the needs of the other parts of the body than by maintaining any particular rhythm of the heart with reference to its own activity. In other words, the heart muscle seems able to act rhythmically for a long time in the presence of normal circulatory conditions without the influence of the nervous system, but it is not able to act in such a manner as to adapt the heart's action to changing somatic conditions without the nerve influence.

The Vomiting Center

This center lies closely associated with the sensory nucleus of the vagus. It receives impulses from the following sources:

I. From the gastric division of the sensory fibers of the vagus.

II. From the sensory fibers of the vagus distributed to other viscera.

III. From the nucleus gracilis and cuneatus, but mostly by way of the gracilis from the sensory impulses from the pelvic organs. Thus the vomiting associated with dilatation of the urethra or the cervix uteri, or with the presence of abnormal conditions in the pelvis generally.

IV. From the nuclei of the vestibular nerves.

V. From the cerebellum. Probably the viscero-sensory neurons of the indirect sensory pathway are thus transmitted to the vomiting center.

VI. From the basal ganglia. The presence of objects of disgust, or even of disgusting thoughts, may cause stimulation of the vomiting center.

VII. Rarely, impulses from the cortical centers seem to be efficient in stimulating the vomiting center. Usually the only volitional impulses causing vomiting act indirectly, by increasing the intra-abdominal pressure, or by compelling the thoughts to dwell upon the act, and thus lowering the liminal value of the center through the basal ganglia centers.

The vomiting center may be acted upon directly by poisons in the blood.

Impulses from the vomiting center are carried as follows:

I. To the splanchnic centers, causing reversed peristalsis. This may be observed by stimulating these centers after section of the vagus. Stimulation of the splanchnic segments of the cord produce reversed peristalsis after section of both vagi, and sometimes after section of either vagus.

II. To the centers for the phrenic, abdominal and intercostal nerves.

III. To the cardio-accelerator and cardio-inhibitor centers, increasing the heart's beat.

IV. To the respiratory center, bringing the respiratory movements to the aid of the act of vomiting.

V. To the salivary center, increasing its action.

VI. To the deglutition center, inhibiting its action.

VII. To the sweat center, increasing sweat.

VIII. To the vaso-motor center, first raising, then lowering, blood pressure.

The cells of the vomiting center may act abnormally under several conditions. The center may be overstimulated by recurrent abnormal conditions, so that even normal stimuli may suffice to initiate vomiting, and severe malnutrition may occur. The cells may be affected abnormally by poisons in the blood stream so that more or less constant activity results. This stimulation may cause frequent vomiting, or it may simply produce enough of the conditions associated with vomiting to prevent eating, or to cause the sense of nausea.

The Sweat Centers

These are bilateral. They act in unison, though it is possible to stimulate them experimentally so that one side of the body may be moist, while the other side remains dry.

The sweat centers receive impulses as follows:

I. Impulses from the heat centers cause the sweat to be increased or decreased according to the temperature requirements of the body.

II. Impulses from the centers concerned in the emotional reactions may increase or decrease the sweat. This is evident in the presence of many emotional states, in which the sweat may fairly drip from the face. The so-called "cold sweat" of fright is due to the increase of sweat secretion, together with the vaso-constriction of the blood vessels of the skin.

III. Impulses from the other medullary and pontine cen-

ters affect the sweat center. The sweating in vomiting is due to this relationship.

IV. Impulses from the centers for the sensory nerves may increase or decrease the secretion of sweat. Irritation of the skin over any considerable area, without pain, may cause sweat. Severe pain may cause profuse sweating. Impulses from the orifices of the body may cause profuse sweating without necessarily being associated with much pain. Dilatation of the anus, or urethra, or the vagina, or the cervix uteri may thus arouse increased sweating. The impulses concerned in these reactions are carried by the fasciculus gracilis to the nucleus gracilis, and thence to the sweat centers.

The sweat centers are also affected by the character and pressure of the blood flowing through them.

Impulses from the sweat centers are carried to subsidiary centers in the cord, in the gray matter between the second thoracic and the second lumbar segments. The axons of the lateral horn cells of these segments pass as white rami communicantes into the sympathetic ganglia, where they enter into the formation of the pericellular baskets of the sympathetic ganglia. The gray fibers of the sympathetic cells pass chiefly with the cerebro-spinal sensory nerves to be distributed to the sweat glands in the skin.

The Pilo-motor Center

The evidence for the existence of a pilo-motor center is not conclusive. The facts supporting its existence indicate its place near the sweat center. It must be affected much as the sweat center is affected, and its impulses must pass over about the same path as that followed by the impulses concerned in the nervous control of sweat.

The muscles of the hairs of the body are contracted in cold and under the influence of fear and certain other emotional states. The phenomenon of "goose flesh" is due to

this contraction of the hair muscles, which is a rather amusing effort to increase the heat of the body by raising the hairs. In the case of fright or anger the effort is to increase the apparent size of the body by raising the hairs, in order that a more ferocious appearance may affright the enemy, and also in order that the attack of the enemy may not be permitted to cause such deep wounds because of the protection of the erect exoskeleton.

Deglutition Center

This center is located near or with the motor center for the vagus nerve.

I. It receives impulses from the centers of the trigeminal, the glosso-pharyngeal, and the superior laryngeal branch of the vagus. These initiate the normal act of deglutition.

II. It receives impulses from the other medullary centers. Thus the act of forced inspiration inhibits deglutition.

This center sends impulses to the motor centers of the trigeminal, facial, vagus and hypoglossal. The movements concerned in the complex act of deglutition are synchronized and coördinated by the activity of these centers.

The deglutition center sends inhibiting impulses to the respiratory center, the heart center, and probably others of the medullary and pontine centers. Dilatation of the pupils follows repeated forced acts of deglutition.

The action of the deglutition center is rarely rendered abnormal except by actual paralysis of the muscles involved or destruction of the nerve cells themselves. Rarely, hysterical paralysis or overactivity of this center may be found.

The Sucking Center

This center is well developed and functional at birth. It is of interest in the fact that its function seems to be lost, at least in some cases, after infancy. It is stimulated to action

in part through sensory impulses, as in the case of the deglutition center, and in part by the physiological conditions of the center itself. It seems to act more in the quality of an automatic center than do most of the other nerve centers.

The Salivary Center

The center which controls the secretion of saliva lies in the neighborhood of the terminal nuclei of the glosso-pharyngeal and the mandibular division of the trigeminal. Its exact location is not known. This center receives impulses from the following sources:

I. Sensory impulses from the glosso-pharyngeal, the trigeminal and sensory part of the facial nerves cause the secretion of saliva which is purely reflex. This may be caused by stimulation of the nerve endings concerned in taste, or by the nerves of common sensations.

II. Impulses from the basal ganglia may increase or decrease the secretion of saliva. The dryness of the mouth in cases of certain excitements, as in stage fright, or the frothing associated with violent emotional disturbances, is thus produced.

III. Impulses from the cortical neurons indirectly affect the activity of the center. The reaction in this case is probably due to the effect upon the lower centers. The optic thalamus has been found concerned in the reaction in some cases, though other tests seem to deny the place of the thalamus in the secretion of saliva. The sight, smell or thought of food causes increased secretion only when these phenomena are associated with at least a certain degree of desire. The thought or sight of substances known to be sour, as a lemon, or juicy, as an orange, may cause increased secretion through the fact that the thought of the taste of the acid or the feeling of the flowing juice stimulates the memories of past experiences, and thus the reaction occurs through the intermedia-

tion of the lower centers, as if the actual taste and feeling were present. This form of psychic secretion is not properly termed reflex. The value of the thorough chewing and tasting of food lies in the psychic stimulation of the salivary center. It is not possible to increase the secretion of the saliva directly by voluntary action, though the use of stimulating movements of the tongue and lips in the effort to initiate the reflex activity of the salivary center is well known.

IV. The impulses from other centers in the medulla, pons and midbrain affect the activity of the salivary center. This is noted in several ways. Vomiting stimulates secretion of saliva, as does also the act of chewing. In sucking saliva is increased.

The salivary center sends impulses to the following structures:

I. Impulses pass to the upper thoracic segments of the cord, thence by way of the lateral horn cells, the white rami, the sympathetic chain, and the superior cervical ganglion to the blood vessels of the salivary glands, and to the gland cells themselves.

II. Impulses pass by way of the facial nerve and the chorda tympani nerve through the submaxillary ganglion (sympathetic) and by way of the facial and the lesser superficial petrosal through the otic ganglion (sympathetic) to the gland cells and their blood vessels.

The activity of the salivary center may be affected by substances circulating in the blood stream. This is not the normal condition, but may be found in certain intoxications. Certain drugs greatly increase the amount of the saliva.

Abnormal positions of the mandible may affect this secretion, probably through the action of the abnormal sensory impulses carried by way of the fifth cranial nerve.

The "paralytic secretion" of bulbar paralysis is of interest in this connection.

The Pupilo-dilator Center

A center for the dilatation of the pupil lies in the upper part of the floor of the fourth ventricle. This center is subsidiary to the centers in the superior colliculi, and it relays the fiber paths from the nuclei of the colliculi to the ciliospinal center.

Other Centers

Other centers exist in the medulla and pons which have not been well studied. The injury of certain areas, for example, may cause the condition of diabetes mellitus; another injury may cause, or seem to cause, diabetes insipidus. The secretion of bile seems, in some cases, to be affected by injuries of the medulla, though whether it is the secretion itself or the contraction of the bile ducts, which thus seems to depend upon the activity of these more or less hypothetical centers, is uncertain.

CHAPTER XIV

THE CEREBELLUM

The cerebellum together with the pons represents the full development of the metencephalon. It is a fair representative of the complexity of relationship which characterizes those nerve centers whose functions have been subject to changes during their phylogenetic development.

In the lowest vertebrates the metencephalon consists of a segment scarcely more differentiated than is any other segment of the neural axis. A prolongation from the lateral aspect of the metencephalon represents the beginning of a cerebellum. It receives, at first, only the terminals or collaterals from those sensory cells of the second order which receive the impulses from the lateral line sensory organs. (These organs, it should be remembered, are represented in the adult mammal only by certain of the structures of the middle ear.) In fishes of a somewhat higher order the cerebellum receives also terminals and collaterals from the secondary gustatory nucleus. Later, the fibers from the mesencephalic nuclei, concerned in the reception of impulses of sight and hearing, and from the gracile and cuneate nuclei, concerned in the reception of the sensory impulses from the body tissues, are received. The ascending cerebellar fasciculi are of more recent origin. Among fishes the cerebellum is very well developed, especially in the direction of the coördination of the sensory impulses. The life habits of fishes require this delicate

coördination in order that they may retain their position while floating in a medium of about the same specific gravity as their own bodies.

With the beginning of the land habits in amphibia the cerebellum becomes a less conspicuous object in the nervous system. The disappearance of the lateral line organs causes a large part of the nerve fibers to the cerebellum to be lost. With the more exact vision and the more need for reactions to answer speedily the stimulation received from a single sense organ, the need for wide coördination of sensory impulses becomes superseded by the need for a more exact coördination of efferent impulses. Thus it happens that we have the appearance of an organ of great efficiency in one class of vertebrates, becoming of less importance in another, and later reaching an efficiency along slightly different lines, far surpassing the primitive development.

From the lower amphibians to man the development of the cerebellum has progressed in the direction of increasing the coördination of the efferent rather than the afferent impulses. This end is secured, in part, by means of the very wide sensory connections, the foundation for which was laid in the fish cerebellum, in part by the development of more distant sensory connections, and in part by the development of other connections with higher centers, and by the increasing complexity of the relations of all of these.

The structure of the cells of the cerebellum itself has changed comparatively little. The axons of the Purkinje cells remain the sole efferent path of impulses from the cerebellar cortex. The incoming impulses, whether from sensory nuclei, lower centers, midbrain, or the cerebral cortex itself, are, so far as our present knowledge can say, limited to the primitive simple methods of receiving; the incoming fibers either terminate in brushlike endings in connection with the brushlike endings of the granule dendrites, or they exhaust themselves

Fig. 55. Section across cerebellar convolution, adult woman. Semidiagrammatic. 72 diameters.

Fig. 56. Longitudinal section through cerebellar convolution, adult woman. Semidiagrammatic. 72 diameters.

Fig. 53. Cells from the cerebellum of half-grown kitten. A—Granular layer. B — Molecular layer. 10 diameters.

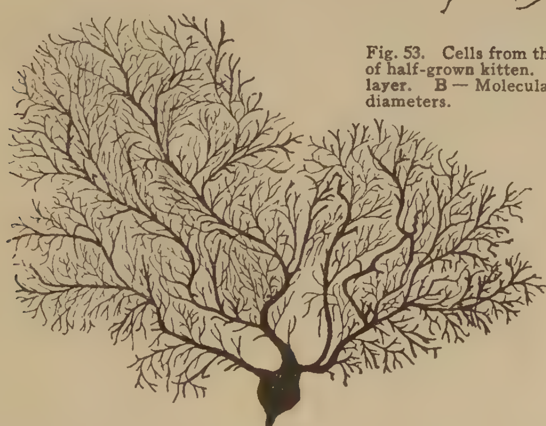


Fig. 54. Purkinje cell from cerebellum of man 63 years old. 175 diameters.

by fine branchings, which apply themselves to the dendrites of the Purkinje cells. It is not possible to localize the fibers from the different parts of the nervous system in the cerebellum with any exactness.

The histological structure of the cerebellum is as complex as its phylogenetic development would indicate.

The cortex presents two layers, between which lie the bodies of the Purkinje cells. These cells are sometimes classified as a third, or ganglionic layer.

The outer or molecular layer is so called from the presence of a number of very small nerve cells. (Fig. 53.) The cells of the outermost part of this layer are very small multipolar cells, whose axons exhaust themselves by repeated branchings in the immediate neighborhood of the cell body. They are a form of the Golgi Type II cells. In the deeper part of the molecular layer are found the stellate or basket cells. These are of stellate form, multipolar, with freely branching dendrites. Their axons pass along the deeper part of the molecular layer, in a direction parallel with the direction of the folds of the cerebellar cortex. Thus, in order to secure sections showing these axons it is necessary to cut the convolutions of the cerebellum longitudinally. (Fig. 56.) From these axons collaterals are given off, which descend to the bodies of the Purkinje cells and break up into a feltwork of fibrillæ, which make a basket around the bottle-shaped bodies of the Purkinjes. (Fig. 18.) The number of collaterals from any given axon of the basket cell seems to be very large. (I have seen seven collaterals from one such axon in one section of Golgi material.)

The molecular layer contains a very large number of nerve fibers. These include the following:

Axons from the small granules of the granular layer pass through the molecular layer to the periphery, divide in a T-shaped manner, and pass tangentially along the cortex.

From these branching axons collaterals descend into the molecular layer to form synapses with the nerve cells therein.

The dendrites of the Purkinje cells branch freely among the cells of the molecular layer. The axons of the Purkinje cells give off collaterals, which pass toward the cerebellar cortex through the molecular layer, and form synapses with the multipolar cells. In the molecular layer are also the climbing fibers of the cerebellum.

The middle or ganglionic layer, as it is sometimes called, is composed of the bodies of the Purkinje cells. (Fig. 54.) These are large and bottle-shaped, and their bodies are closely invested by the basketlike branchings of the collaterals of the axons of the stellate or basket cells of the molecular layer. The dendrites of the Purkinje cells are characteristic. They branch very freely in one plane within the molecular layer. The dendrites are beautifully tree-shaped, and the whole cell presents a very striking appearance in sections prepared after the method of Golgi. The plane of division of the dendrites is placed at right angles to the direction of the convolutions, so that if one wishes sections showing the dendrites of the Purkinje cells, it is necessary to cut the convolutions crosswise. (Fig. 55.) The dendrites of the Purkinje cells are closely followed by the branchings of the climbing fibers.

The inner granular layer is so called from the appearance of its most abundant cells. These are called granules, and include two classes, large and small granules. The granule cells are alike in form. They are multipolar, and their dendrites terminate in peculiar, brushlike end tufts. (Fig. 53.) These end tufts are in close relationship with the similar brushlike terminations of the collaterals and terminals of the moss fibers of the cerebellum. The small granule cells have long axons, which penetrate the molecular layer, branch in a T-shaped manner, and run tangentially along the cortex, giving off collaterals to the cells of the molecular layer at

intervals. The large granules are of the Golgi Type II class. Their axons exhaust themselves by repeated branchings among the dendrites and axons of their immediate neighborhood.

Through the granular layer the axons of the Purkinje cells pass as they leave the cortex; through this layer also the collaterals from these axons pass toward the cortex. The entering climbing and moss fibers penetrate this layer in reaching their destination.

Beneath the granular layer is found the cerebellar medulla of white fibers passing to and from the cortex. These fibers are supported by neuroglia cells.

This white matter includes fibers of two classes, neither of which is as well known as is desirable.

The climbing fibers enter the cerebellum, but their origin is not certainly known. They probably enter by way of the restiform body or the brachium pontis. They pass to the cortex, branch freely, and apply themselves to the dendrites of the Purkinje cells, which they follow to their ultimate extremities.

The moss fibers enter the cerebellum, but their origin is not known. They branch freely, and their collaterals and probably also their terminals break up into the brushlike end tufts already described for the granule cell dendrites, and closely applied to them.

The axons of the Purkinje cells pass downward through the white matter, and they alone are corticifugal. It is not certainly known whether most of the Purkinje cells terminate in the dentate nucleus, or whether most of them leave the cerebellum. Part of them certainly stop in the dentate nucleus.

When it is remembered that the dendrites of the Purkinje cells branch widely in a plane at right angles to the direction of the convolutions, that these widely-branching dendrites are thoroughly permeated with the collaterals and axons of the multipolar cells of the molecular layer, with the tangential

Fig. 57. Section through nucleus dentatus, adult woman. 10 diameters.

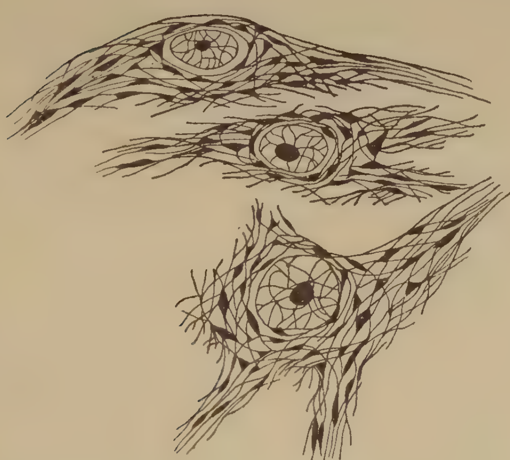


Fig. 58. Cells of nucleus dentatus from same section as Figure 57. 800 diameters.

fibers of the axons of the small granular cells, and with the axons of Golgi Type II cells; when it is remembered also that the axons of the stellate cells pass parallel with the direction of the convolutions, and thus at right angles to the direction of the Purkinje dendritic plane, and that a considerable number of Purkinje cells may receive the basketlike terminations of any one stellate axon, then the complexity of this structure may in part be realized. The recurrent collaterals of the Purkinje axons add to the intricacy of the arrangement.

The masses of gray matter centrally placed require much more study. The nucleus dentatus is the largest of these masses. It is found in the lower animals as a single mass of gray matter of simple form. In the human cerebellum it presents the characteristic dentate appearance, very much like that of the olive. Its phylogenetic development is not known. It may represent an infolding of the cerebellar cortex. (Figs. 57, 58.)

The nucleus emboliformis is placed at the hilum of the dentatus, like a cork for that structure. The globosus lies mesially from the emboliformis. These nuclei present some evidence of being of phylogenetic descent from the secondary gustatory nucleus of fishes. The fibers of the anterior ascending cerebellar fasciculus pass into these nuclei, but whether the axons terminate in part or as a tract, or whether they pass without relay to the cortex, is not certainly known.

The nucleus tectis lies in the roof of the V-shaped ventricle. It seems to represent an infolding of the cortex.

The cerebellum receives nerve impulses from very nearly all parts of the central nervous system, and since this includes all or practically all of the sensory neurons, both visceral and somatic, it follows that the cerebellum receives impulses from the entire body.

The connections of the cerebellum are as follows:

I. Somatic sensory neurons of the first order may send

axons or collaterals to the superior vermis by way of the restiform body. This includes the fibers of the fasciculus gracilis and fasciculus cuneatus, which pass into the restiform body without relay, and the fibers of cranial sensory nerves, which may follow the same path.

II. Visceral sensory neurons of the first order may send axons or collaterals to the cerebellum by way of the restiform body. Probably these include very few fibers.

III. Somatic sensory neurons of the second order send many axons and collaterals to the cerebellum, chiefly by way of the restiform body from the nucleus gracilis, nucleus cuneatus and the cranial nerve nuclei of termination. These seem to reach the cortex of the superior vermis.

IV. Visceral sensory neurons of the second order send many axons to the superior vermis cortex. These include the fibers of the anterior ascending cerebellar fasciculus (direct cerebellar), which passes by the restiform body, and a part of the posterior ascending cerebellar fasciculus (Gower's tract), which passes through the medulla and pons and sends some fibers by the brachium conjunctivum (superior peduncle) into the cerebellum.

V. Axons or collaterals from the nucleus pontis pass to the cortex of the hemispheres of the cerebellum. For the most part these axons pass to the contra-lateral hemisphere, but a few of them pass to the hemisphere of the same side.

VI. Axons of cells of the red nucleus have been said to enter the cerebellum by way of the brachium conjunctivum. This connection has been doubted by later studies. It seems probable that a small number of fibers from the red nucleus to the cerebellum pass by way of a bundle in the brachium conjunctivum.

VII. The cells of the olive send axons to the cerebellum, but whether to the dentate nucleus or to the cortex is not known.

The cerebellum sends impulses by almost as varied pathways.

I. The axons from the cells of the nucleus dentatus make up the larger part, if not all, of the brachium conjunctivum (superior peduncle). These axons terminate, for the most part, in the red nucleus, but also in part in the quadrigeminates and the optic thalamus. The brachium conjunctivum fibers decussate immediately after emerging from the cerebellum. These fibers probably carry impulses concerned in consciousness of heat, cold, pain, muscular effort and the various visceral sensations.

II. Axons from the cells of the cortex of the cerebellar hemispheres pass by way of the brachium pontis (middle peduncle) to the nucleus pontis, mostly contra-lateral, but partly to the same side.

III. Descending axons either from the cortex (the Purkinje cells) or from the dentate nucleus pass downward through the cord, forming synapses with the cells of the central and postero-lateral gray matter, and through them affecting the activity of the cells of the anterior and the lateral horns of the cord.

IV. Axons from either the cortex or the dentate nucleus pass by way of the restiform bodies to the olive, the medullary centers, and the motor cranial nerve nuclei. Very little is known of the various relationships.

Functions of the Cerebellum

The functions of the cerebellum have been the subject of much study. Experimental evidence is almost as much at variance with clinic evidence as the different manifestations of clinic evidence vary among themselves. It seems to be well proved that the cerebellum is chiefly concerned in the maintenance of the tome of the visceral and somatic muscles, the maintenance of equilibrium, the coördination of complex move-

ments, and with the transmission of visceral and certain common somatic sensations to the cortex. These functions are of great importance, yet widespread disease of the cerebellum may be associated with few or no localizing symptoms. In the presence of tumors or other lesions involving the cerebellar hemispheres it is rare for a diagnosis to be made antemortem unless the peduncles are involved. Lesions of the vermis are sometimes recognized, but it sometimes happens that even vermis lesions escape recognition until postmortem.

Stimulation of the cerebellar hemispheres in the anesthetized animal produces no perceptible effects. Stimulation of the central gray matter may be followed by contraction of the muscles, chiefly those of extension of the same side of the body, if the basal ganglia remain intact. Section of the brachium conjunctivum precludes this reaction. Stimulation of the brachium pontis is followed by contraction of the muscles, chiefly those of extension of the same side of the body. These movements include the diaphragm and the intercostals. No visceral effects have been seen to follow any stimulation of the cerebellar tissues. Stimulation of the restiform body produces no perceptible effects.

Diseases of the cerebellum are rather rare and are not always to be recognized. The gross lesions include those found in any other part of the brain — abscesses, gummata, tubercles, etc., and the symptoms produced are often not very well related to the normal functions of the cerebellum, as indicated by its structural relationships.

The removal or injury of a considerable part of the cerebellum is followed by a loss of muscular power and of coördination on the same side of the body. There is no perceptible loss of sensation. There may be or may not be muscular tremors and athetosis. If the injury is not progressive, and the subject is not too old, there is later produced some effort at compensation, either upon the part of the cerebellum left

intact, or by other centers capable of coördinating the impulses concerned in producing the complex actions of the skeletal muscles. No symptoms referable to an injury of the viscero-sensory paths have been described in cerebellar disease.

The cerebellum, as one of the nerve centers, must depend for its normal activity upon the same conditions which affect the other nerve centers; that is, the cerebellum depends for its food supply upon the blood brought to it. This blood must be good, clean, and kept rapidly flowing if the cerebellar cells are to maintain their proper activity. This activity also depends upon the receipt of certain impulses from the other parts of the nervous system already described. In the lack of these impulses, or if they should be rendered abnormal in any way, the normal coördinations are not found. It is doubtless true that many of the mistakes made by weary people, or by people whose bodies are in any way subnormal, may be due to one of two conditions — either the cerebellar cells are poorly nourished and are thus inefficient, or the nerves carrying sensory impulses, or other impulses, to the cerebellum are not such as to lay the foundation for normal coördinating activities in the cerebellar cells. It is by means of this relation that many of the accidents called "careless" are produced by persons who are neurotic or poorly nourished, or whose nerve cells have a lower liminal value than usual for any reason. During childhood the progressive development of the neurons concerned in the higher unconscious coördinations may be associated with periods of poor coördinations. Children at this age are, no doubt, often blamed for the awkwardness and carelessness, due, in large part, to the delayed or unbalanced development of the cerebellar neurons, or of the neurons upon whose activity the coördinations depend.

CHAPTER XV

THE MIDBRAIN CENTERS

The midbrain is derived from the middle cerebral vesicle. It is proportionately less well developed in the higher vertebrates, especially the higher mammals, because of the enormously greater development of the cerebrum. The midbrain is, however, actually better developed, in certain senses, in the higher mammals, and especially in man, since it is here that we find the greater differentiation of the mesencephalic cells and the greater specialization of the midbrain functions.

The midbrain in man is about a half inch in the antero-posterior direction, rather more than an inch in vertical diameter, and from an inch to one and a half inches transversely. It is traversed by a channel, the cerebral aqueduct, or the aqueduct of the cerebrum, or the aqueduct of Sylvius, or the iter a tertio ad quartum ventriculum, as it is variously called. The aqueduct is about a half inch in length. It is continuous anteriorly with the third ventricle, and posteriorly with the fourth ventricle. It is lined with columnar epithelium, which is ciliated during embryonic life in all vertebrates studied, and the cilia may be found throughout life in some animals.

The posterior aspect of the midbrain is occupied by the quadrigeminate bodies. The superior colliculus is composed of the anterior pair of the quadrigeminates, which are sometimes called the nates. The inferior colliculus is composed of the posterior pair, which are sometimes called the testes.

The superior surface of the midbrain is continuous with the thalamus and the bases pedunculi.

The anterior or ventral aspect presents a deep median sulcus, on either side of which lie the convex surfaces of the peduncles of the cerebrum. External to the curving surface the shallow oculo-motor groove shows the superficial origin of the third cranial nerve.

The inferior surface is continuous with the pons and the superior brachium.

The Corpora Quadrigemina

The quadrigeminate region shows considerable changes in its phylogenetic development. In the lower fishes the midbrain is composed of a simple tube corresponding to two segments or neuromeres. With the progress of cephalization the thickening of the roof of these segments gives place for the termination of certain of the sensory tracts — the axons of the sensory neurons of the second order from the somatic and visceral sensory nuclei of the medulla and pons, the nucleus gracilis and nucleus cuneatus and the sensory nuclei of the fifth, seventh, eighth, ninth and tenth cranial nerves, and the axons of the second or third orders from the retina. In lower fishes these sensory terminations seem confused and intermingled inextricably. With the increasing development of the quadrigeminates the roof of the midbrain broadens and the aqueduct is proportionately widened, so that it approaches the size of the other ventricles. The quadrigeminates in the lower fishes seem to represent the place of most exact coördination of the nerve impulses concerned in adapting the bodily movements to the environmental changes. The efferent impulses are carried by paths similar to those of higher animals to the somatic muscles of the entire body.

In the amphibia the lateral line sense organs are not found, the eyes are of comparatively less biological value than

in fishes, and there is less need for delicately coördinated muscular movements on land than in water. The quadrigeminal region is found very much less developed in amphibia for this reason. The increase in the cephalization begins to overshadow the quadrigeminates, also, and a beginning of the accumulation of the cells concerned in the auditory impulses in the posterior portion and of the cells concerned in visual impulses in the anterior portion is found in amphibia. The aqueduct regains its small size.

In birds another change is found. Birds find visual impulses of great value, and their muscular movements must be subject to delicately coördinated nerve impulses. The midbrain in birds attains considerable development, both in the connections of the neurons concerned in vision and also in the connections with the lower centers. The tecto-spinal tract in the anterior longitudinal bundle is here, as in fishes, of great value in securing the muscular coördinations necessary to the maintenance of equilibrium. The birds show no division of anterior and posterior colliculi, partly because the differentiation of the midbrain roof nuclei is not complete, and partly because of the comparatively less development of the auditory centers, and the less important biological value of the auditory impulses.

In mammals the specialization of the quadrigeminal region is fairly complete. The development of the higher centers leaves the sensory supply of the quadrigeminates comparatively scanty, while the retention of certain sensory connections with these cells, whose axons yet pass toward certain motor nuclei, has led them to assume the less general and more highly specialized functions concerned in the coördination of the eye and ear movements, nutrition and control, and in the control of those other structures whose activity affects the eye and ear tissues or functions, or whose activity the auditory and visual impulses may affect.

Superior Colliculus

The superior colliculus is composed of two bodies, one on either side. These bodies present a more complex structure than do those of the inferior colliculus.

The superior colliculus receives about one-fifth of the fibers of the optic tract. These fibers circle around the body, making its external layer of fibers. A layer of neuroglia invests the outer aspect of this layer. These fibers enter the mass of the body, and form synapses with the cells of the deeper layers. The more superficial cell layer is composed of cells somewhat resembling those of the cerebral cortex. They are small, polygonal and multipolar, sometimes spindle-shaped. This layer is separated from the lower layer of cells by white fibers, partly those of the optic tract, partly those from the occipital cortex, and partly other unidentified fiber tracts. The deeper cells are larger, multipolar and pyramidal, and have very long and complexly dividing dendrites.

The structure of this body is described as being composed of six layers:

(1) The neuroglia layer, (2) optic fiber layer, (3) layer of small nerve cells, (4) inner medullated layer, (5) layer of large nerve cells, (6) central gray matter around the aqueduct.

The superior colliculus receives impulses from the following sources:

I. The optic tract is, in mammals and man, the most important source of impulses.

II. A few fibers from the medial fillet enter the body. This represents an important original relationship, now superseded to a great degree.

III. Fibers from the thalamus and other neighboring centers bring the activity of all into normal relationship.

IV. Descending fibers from the cortex, chiefly of the occipital lobes of the same side, enter the body. The impulses

carried by these fibers are concerned in the nutrition of the eyeball and related tissues, in some manner not understood.

V. Ascending fibers from the cerebellum by way of the brachium conjunctivum reach the body. These fibers probably carry two classes of impulses: First, the indirect visceral sensory impulses are carried to the body, partly as a remnant of the primeval relationship, and these are manifest in the injury to the functions of the eye produced in certain forms of visceral disturbance. A second class of fibers carried from the cerebellum to the superior colliculus carry the impulses from the cerebellum, which bring the eye movements into coördinate relationship with the other somatic muscles.

Impulses from the superior colliculus are carried to the following destinations:

I. Fibers, axons of the cells of the superior colliculus, probably both of the large and the small cells, pass around the aqueduct to end about the cells of the viscero-motor and the somato-motor nuclei of the third cranial nerve, and of the somato-motor nuclei of the fourth and sixth cranial nerves. In this way the direct reflexes of the eye are coördinated.

II. Impulses are carried, either directly or through the intermediation of other neurons, to the pupilo-dilator center in the pons.

III. Impulses are carried to the vaso-motor center in the lower part of the medulla. These are concerned in the control of the circulation of the orbital structures.

IV. Impulses are carried by way of the tecto-spinal tract in the anterior longitudinal bundle to the cilio-spinal center in the upper thoracic segments of the cord.

V. Impulses are carried by the same pathway to the segments of the cord through its whole extent. These are reminiscent relations; and while the impulses so carried are probably of a certain value in the maintenance of muscular tone, it is not probable that they are of any great importance.

In diseases affecting the quadrigeminates no loss of muscular tone is perceptible.

VI. Efferent fibers from the superior quadrigeminates pass with the optic nerve to the retina. In the injury of these fibers the nutrition of the retinal tissues, and, indeed, of the eyeball generally, is rendered abnormal.

VII. Fibers from the body are carried to other neighboring gray masses, partly as reminiscent structures and partly as a means of securing coördinate action.

The Inferior Colliculus

The inferior colliculus is composed of the two posterior quadrigeminate bodies. These bodies have a less complicated structure than do the superior bodies. (Fig. 59.) They are smaller, and contain only a single group of multipolar nerve cells. The brachium conjunctivum passes the inferior colliculus on its ventral and lateral aspects.

The inferior colliculus receives a large part of the fibers from the lateral fillet. Thus the body is concerned in coördinating the reflexes of the auditory structures. It receives impulses from the following sources:

I. The most important incoming stream of impulses is from the auditory nuclei by way of the lateral fillet. A few fibers, the axons of the cochlear ganglion cells, pass directly to the inferior colliculus. Other fibers are axons of the terminal nuclei of the auditory nerve, others are from the superior olive and the nucleus of the trapezoid body.

II. Fibers from the internal geniculate body and thalamic nuclei pass to the posterior quadrigemina by way of the posterior brachium. These also are concerned in the coördination of the auditory reflexes.

III. Descending fibers from the temporal lobes terminate in the inferior quadrigemina. These are concerned in carrying the efferent impulses to the auditory structures, as

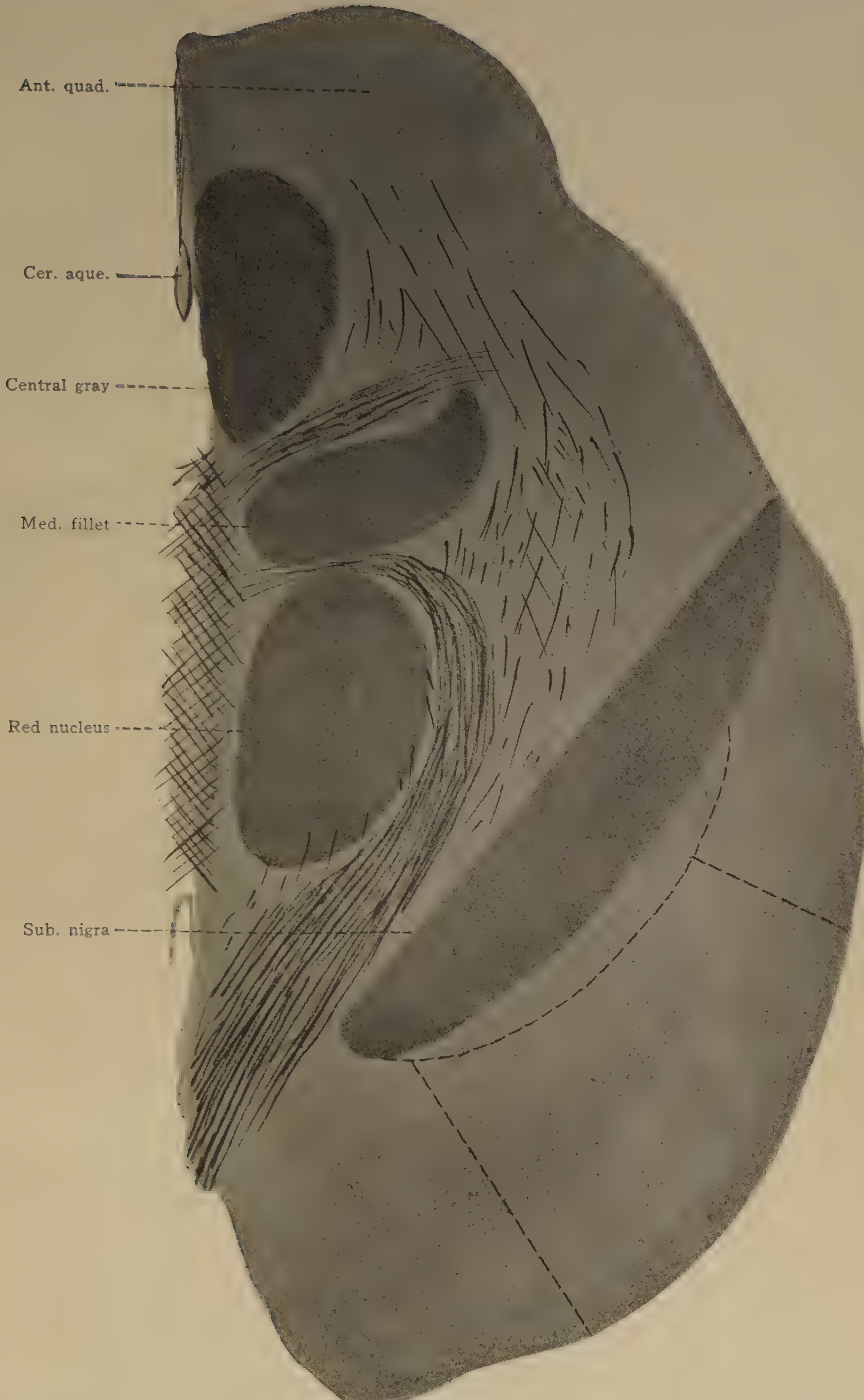


Fig. 60. Section through the midbrain of adult woman. The central gray matter lies around the aqueduct. The lateral fillet is not shown. The decussation of the brachium conjunctivum is indicated. Below the substantia nigra lies the basis pedunculi. Next the substantia is the intermediate bundle, a striato-pontine bundle. The outer fifth of the basis is occupied by the temporo-pontal tract, the middle three-fifths by the pyramidal tracts, the inner one-fifth by the fronto-pontal tract. 5 diameters.

homologous fibers are concerned in the nutrition of the orbital tissues.

IV. Fibers from the medial fillet enter the posterior quadrigemina. These are probably reminiscent fibers, since the earlier colliculus received somatic sensory and viscerosensory fibers.

Fig. 59. Section through posterior quadrigeminates of kitten 4 weeks old. The aqueduct is just opening into the fourth ventricle. The nucleus of the fifth cranial nerve lies at the angle. Nearer the median line the lower part of the red nucleus is shown. The crescentic substantia nigra lies at the junction of the lower with the middle third of the surface shown. 10 diameters.

V. Ascending fibers from the dentate nucleus of the cerebellum reach the body. These probably carry impulses of two classes: those of the indirect visceral sensory path, which must be largely reminiscent, and the impulses from the cerebellum itself, concerned in the coördination of the ear muscle

movements with the movements of the muscles of other parts of the body.

The posterior quadrigemina send impulses to the following structures:

I. Impulses pass to the motor nuclei of the trigeminal and facial nerves, especially to those portions of these nuclei which control the ear muscles, but also to the portions which control other muscles of the head and face.

II. Impulses pass to the nuclei of the oculo-motor, the trochlear and the abducens. In this way the movements of the ear and the eye are properly related to one another.

III. Impulses pass to the vaso-motor center in the medulla. In this way the circulation through the ear tissues is in part controlled.

IV. Impulses are carried by the tecto-spinal tract to the spinal cord at all levels. These fibers, while perhaps slightly functional in maintaining muscular tone and the equilibrium of the body, are probably chiefly reminiscent.

V. Fibers from the inferior colliculus pass downward to the nuclei of the auditory nerves, and probably from these in the auditory nerve to the cochlea. In part the impulses carried by this path are relayed in the auditory nuclei.

VI. Impulses from the inferior colliculus are carried to other related ganglia and nuclei.

The quadrigeminate bodies are not often diseased. Their arterial supply and venous drainage are not easily impeded. They are supplied with blood by the ganglionic arteries, branches from the arterial circle of the cerebrum (circle of Willis). They are functional, and thus evade the tendency to disease characteristic of rudimentary structures.

Tumors, gummata and tubercular nodules may affect the quadrigeminates, though rarely. The diagnosis is difficult during life, except in very limited lesions involving recognizable functional centers.

Injuries affecting the superior colliculus are followed ultimately by degeneration of the retina, and, to a certain extent, of the other orbital tissues. There is immediately a lack of coördinate movements of the eyeballs. The manner in which the eyeball is displaced varies according to the location of the lesion and the manner in which the motor nuclei of the cranial nerves are also affected. The unequal dilatation of the pupils may help in diagnosis in some cases of unilateral lesions.

Injuries of the posterior quadrigeminates are associated with a loss of coördination of the ear muscles — the stapedius and the tensor tympani. The nutrition of the ears is interfered with, and deafness soon occurs. This usually affects both ears, but may be most pronounced on the side opposite the lesion.

Beneath the aqueduct the midbrain is composed of two fairly well-differentiated parts. The external layer is of white matter; it extends from the ventral surface to the crescent of pigmented gray matter called the substantia nigra. This external layer of white matter is called the basis pedunculi, or the crusta, in the older terminology. The bases pedunculi are of comparatively recent origin. In the lower vertebrates the tegmentum and the collicular region only are found. The process of cephalization is associated with the development of the longer fiber tracts which transmit impulses upward and downward. The bases pedunculi are made up of these longer fiber tracts, which become necessary with the progressive development of the striate bodies and the cerebral hemispheres.

The bases pedunculi are each composed of three main groups of fibers. These are not to be recognized as different in any way during adult normal life, but they are distinguished by their differing myelinization periods, and by the fact that they undergo degeneration after lesions of different areas of the cortex. (Fig. 60.)

The outer one-fifth of each basis is composed of fibers

called temporo-pontal. They are (1) the axons of cells in the temporal lobe of the cortex and the adjacent areas of the occipital lobe, or (2) axons of cells of the lenticular nucleus, with which the cortical axons form synapses. These axons terminate in the nucleus pontis; from the nucleus pontis the impulses are transmitted to the cerebellum. This is one of the indirect motor pathways. A few fibers pass directly to the cranial nerve motor nuclei.

The median one-fifth of the basis pedunculi is composed of fibers from the frontal lobe to the pons. The axons of the cells of the frontal lobes pass directly by way of this tract to the pons, or they terminate in the gray matter of the thalamus or the striate body, from which axons pass by the same path to the pons. Thus the median and the lateral one-fifth of the basis is composed of fibers carrying impulses from the cortical centers to the pons, whence the impulses are referred to the cerebellum, and from there to the lower motor segments.

The remaining three-fifths of the basis, placed in the middle of crescent, give place for the pyramidal fibers. These are the axons chiefly of the large pyramidal cells of the precentral gyrus. These axons descend through the pons and medulla, giving off fibers to the red nucleus, substantia nigra, nuclei of the reticulum, and to the motor nuclei of the cranial nerves, to the lower part of the medulla. Here about four-fifths of the fibers decussate, and pass on the opposite side of the cord, to be distributed mostly to the centers of the somatic motor nerves of the lower part of the body and the legs. The remaining fibers pass on the same side of the cord until they reach the segment of their termination, when they also decussate, and are distributed chiefly to the centers for the control of the somatic muscles of the upper part of the body and the arms.

Above the three divisions just mentioned lies a strand of fibers called the intermediate bundle. It is homologous with

the external bundles of fibers. It is composed of the axons of cells of the striate bodies, and terminates, for the most part, in the nucleus pontis.

The intermediate bundle is represented, to a certain extent, in the lower vertebrates. It offers transmission to the

Fig. 61. Section through crura cerebri of cat. The aqueduct is lined with epithelium. Beneath, in the middle line, lie the cells of the visceral nucleus of the third nerve, with the somatic motor nucleus laterally placed. Further laterally and beneath lie the cells of the red nucleus, and beneath these the cells of the substantia nigra. The bundles of third nerve fibers are passing toward their superficial origin.

few descending fibers from the developing striate bodies, and probably is concerned in bringing the movements of the body into relationship with the sensory impulses from the olfactory centers.

The Tegmentum

The tegmentum is that portion of the midbrain included between the substantia nigra and the aqueduct. It is contin-

uous with the tegmental region of the pons and medulla caudad, and with the tegmental region of the thalamus cephalad. The tegmentum is composed of fiber tracts, among which lie several groups of nerve cells.

For the most part the fiber tracts of the tegmentum are ascending. (Fig. 61.) The following have been studied:

The Medial Fillet

The medial fillet (lemniscus) is composed of the axons of cells of the nucleus gracilis, nucleus cuneatus, and the nuclei of all the cranial sensory nerves except the cochlear portion of the auditory nerves. All of these fibers decussate, so that the fillet of one side carries sensory impulses from the opposite side of the body. The axons of the nucleus cuneatus and nucleus gracilis pass as internal arcuate fibers just dorsal to the inferior olive, decussate, and turn abruptly forward through the medulla, pons and midbrain. In passing they give some fibers to the motor nuclei of the cranial nerves, and a bundle of considerable size, the superior fillet, to the anterior quadrigemina. A few fibers stop at the inferior quadrigemina. The terminations in the quadrigemina are probably largely reminiscent, though a certain amount of movement of the eye and ear muscles in answer to the bodily sensations may thus be secured.

The fibers of the fillet terminate, for the most part, in the optic thalamus. Probably the main termination for the medial fillet is the lateral thalamic nucleus, though some investigators describe a different course for those axons which arise from the cuneatus (globus pallidus, partly of the same, partly of the opposite side).

The Lateral Fillet

The lateral fillet is the auditory pathway through the midbrain. It is composed of axons of the cells in the (1) cochlear

nuclei, chiefly of the opposite side; (2) nucleus of the trapezoid body, chiefly of the same side; (3) superior olivary body of both sides; (4) nucleus of the lateral fillet of the same side; (5) inferior quadrigeminate body of the same side. These fibers pass together to the medial geniculate body, with whose cells the fibers form synapses. In passing the corpora quadrigemina the lateral fillet gives off fibers to these centers — a large bundle to the posterior colliculi, by means of which the ear movements are in part coördinated, and a few fibers to the superior colliculi, by means of which the movements of the eye and ear are in part related in function.

The Brachium Conjunctivum

The fibers of the brachium conjunctivum (superior cerebellar peduncle) are composed chiefly of the axons of the nucleus dentatus. These decussate for the most part just beneath the aqueduct, and pass forward to the red nucleus, where they terminate. A few pass onward to the lateral nucleus of the thalamus.

The brachium conjunctivum contains also a few fibers which are axons of the cells of the red nucleus, which pass to the nucleus dentatus of the cerebellum.

The Spino-thalamic Tract

This tract is that which apparently arises from the anterior ascending cerebello-spinal tract in the neighborhood of the brachium conjunctivum, though in reality it is probably an individual tract throughout, and only intermingled with the ascending cerebello-spinal in passing upward through the cord.

The fibers of this tract are axons of the cells of the posterior horns of the cord, or the dorsal nucleus, or both, with which the entering axons of the posterior roots form synapses. These axons decussate, or the axons of the posterior horn cells

decussate, in the neighborhood of the segment of the entering root fibers. The tract is so closely intermingled with the anterior ascending cerebello-spinal tract that it is not possible to distinguish them except in degenerating material. The tract passes with the cerebello-spinal to the neighborhood of the brachium conjunctivum, where the cerebellar turns caudad to enter the cerebellum, while the spino-thalamic fibers continue cephalad to the thalamus. In passing through the medulla and pons a few fibers from the nuclei of the cranial nerves of common sensation join the tract and ascend with it. It gives off a few fibers to the superior and the inferior colliculi, which are probably reminiscent, and a few to the substantia nigra, whose function is not known. The chief termination of the tract is in the lateral nucleus of the thalamus. This tract carries impulses aroused on the opposite side of the body by temperature changes and painful stimulations, together with a part of the tactile impulses.

The tegmentum carries also a tract containing both ascending and descending fibers, and a few descending tracts.

Medial Longitudinal Bundle

The medial longitudinal bundle (posterior longitudinal bundle) is composed of an ascending and a descending fasciculus. The ascending part is continuous and homologous with the anterior fasciculus proprius. It is composed of the axons of cells of the posterior and postero-lateral and central regions of the spinal gray matter, and in the terminal nuclei of the cranial sensory nerves, and probably in the nucleus gracilis and nucleus cuneatus. These fibers decussate, chiefly, and terminate about the cells of the motor nuclei of the cranial nerves, both somatic motor and visceral motor, in the quadrigeminate bodies, and a few fibers pass to the lateral nucleus of the thalamus. It is chiefly concerned in the transmission of those impulses necessary to the coördination of the complex

reflex actions, including the muscles of the trunk, limbs and head.

This tract also includes axons of cells in each of the nuclei of the third, fourth and sixth cranial nerves which pass to each of the others of the group, both of the same and of the opposite sides.

The descending strand of fibers is composed of axons of the cells of the superior lateral nucleus of the reticular formation. In the pons it receives the axons from the middle lateral nucleus, and the superior, middle and inferior central nuclei of the reticular formation, and in the medulla the axons of the inferior lateral nucleus of the reticular formation. These fibers pass in the anterior fasciculus proprius of the cord throughout its length (ponto-spinal tract), decreasing in size all the way as it gives off fibers to the lateral part of the gray crescent at all levels. In the medulla and pons and midbrain it gives fibers to the cranial motor nuclei.

The Anterior Longitudinal Bundle

This is almost exclusively a descending tract. Its fibers are the axons of the cells of the quadrigemina, chiefly the anterior colliculus. The fibers decussate almost completely, and pass caudad through the reticular formation into the antero-medial fasciculus proprius of the cord. It gives off most of its fibers to the nuclei of the third, fourth and sixth cranial nerves and to the region of the cilio-spinal center in the upper thoracic cord, but others of its fibers pass through the entire length of the cord, giving off fibers in each segment. This bundle includes very few fibers other than those of the tecto-spinal tract.

The Olivary Bundle

This is a tract whose function is not known. It is composed of axons of cells probably in the globus pallidus of the

lenticular nucleus, and it terminates in the inferior olivary nucleus. Experimental stimulation of the globus pallidus gives no perceptible results, and no accounts of clinic evidence are on record.

The Rubro-spinal Tract

The rubro-spinal tract is composed of the axons of the cells of the red nucleus, which descend to the center of the gray crescent of all levels of the spinal cord. The tract probably carries with it axons of the cells of the subthalamic nucleus (Luys) and of the substantia nigra. These fibers decussate and pass downward through the tegmentum, pons, medulla and cord, giving off axons and collaterals to the motor nuclei, both somatic and visceral, and to the various centers scattered through the gray matter of these structures, including those concerned in both visceral and somatic coördinations. This tract, with the posterior longitudinal bundle, probably carry the impulses concerned in the emotional and instinctive reactions.

Descending Root of the Trigeminal

The motor nucleus of the trigeminal nerve lies in the gray matter under the aqueduct. Its uppermost fibers arise near the opening of the third ventricle, but for the most part they come from the floor of the aqueduct near the opening of the fourth ventricle. These fibers are continuous with the motor fibers of the trigeminal through the pons.

The Gray Matter of the Midbrain

The gray matter of the midbrain includes all or a part of the nuclei of the third, fourth, fifth and sixth cranial nerves. These are discussed elsewhere.

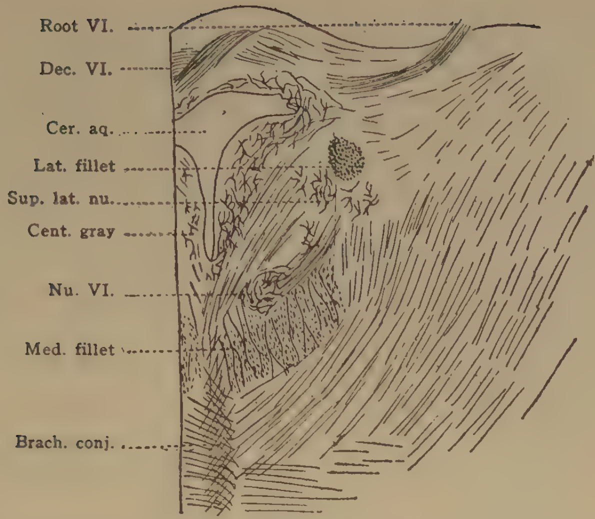


Fig. 62. Midbrain, adult woman. The sweeping fibers of the brachium conjunctivum occupy the outer and lower part of the field. They pass forward as they decussate. 5 diameters.

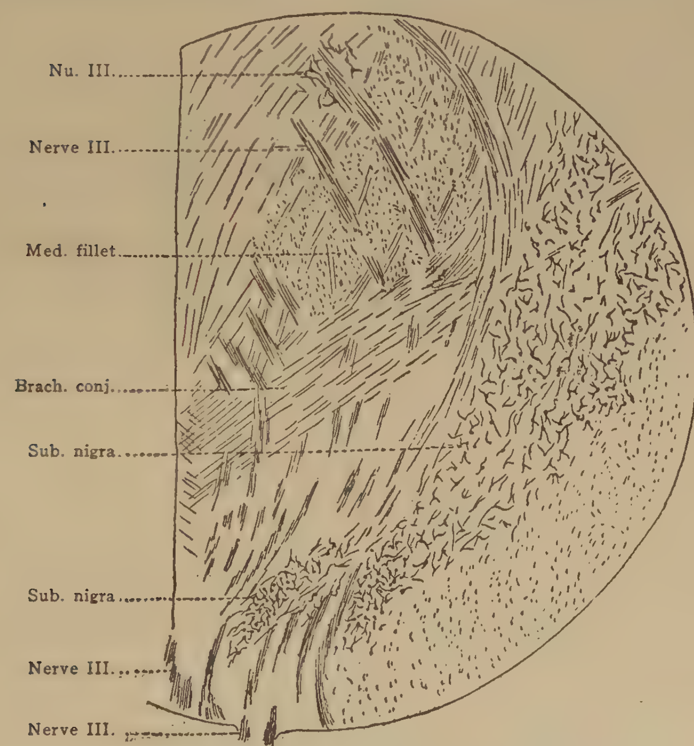


Fig. 63. Origin of third nerve. Section through midbrain, anterior to that shown in Figure 62. Lateral and inferior to the substantia nigra lie the fibers of the intermediate bundle.

The Substantia Nigra

This is a mass of gray matter, containing many cells, which are pigmented. It is a crescentic body, which forms the boundary between the tegmentum and the basis pedunculi. (Figs. 60, 62, 63.) The substantia nigra receives fibers, chiefly collaterals, apparently, from the following sources:

I. From the medial fillet.

II. From the lateral fillet.

III. From the spino-thalamic tract.

IV. From the brachium conjunctivum.

V. From the red nucleus.

VI. From the corpora striata by way of the intermediate tract.

VII. From the pyramidal tracts.

VIII. From the optic thalamus.

IX. From the corpora mammillaria.

The impulses from the substantia nigra are carried, for the most part, by way of the medial longitudinal bundle to the nuclei of the reticular formation. Other connections are with the cranial nerve motor nuclei, the cerebellum by way of the brachium conjunctivum, probably the olivary nucleus, and there is also a direct path with the rubro-spinal tract to the spinal segments through the length of the cord.

The Zona Incerta

The region between the red nucleus and the substantia nigra and the nucleus hypothalamicus is occupied by a mass of interlacing fibers with cells interspersed among them. These cells are rather large, multipolar, and have long, freely-branching dendrites. The destination of their axons is not known, but some of them seem to join the axons of the red nucleus cells and those of the substantia nigra. The cells of the zona incerta are to be considered, probably, as part of the

centers for the coördination of the movements of the emotional and instinctive reactions.

Nucleus Hypothalamicus

The nucleus hypothalamicus (Luys' body) lies dorsolateral to the substantia nigra, with which it appears to be continuous in the cat and the dog. This nucleus resembles the red nucleus in structure. Its cells are polymorphic and multipolar. Some Gogli cells of Type II are included. Into this nucleus pass fibers from the fillets, from the ascending tracts of the tegmentum to a certain extent, from the red nucleus and the substantia nigra. Descending fibers from the globus pallidus terminate in this nucleus. The axons of the intrinsic cells of the nucleus pass to the cerebral cortex, to the thalamus, to the red nucleus and substantia nigra, and to the nuclei of the reticular formation. Some investigators have described fibers from Luys' body to the nucleus dentatus. Axons of the nucleus hypothalamicus enter the putamen and terminate by forming synapses with the cells of that center.

The Pineal Gland

This is not to be considered as a center. It is here mentioned only on account of its relationship with neighboring centers, and on account of its phylogenetic interest.

It is a small body, about one-third of an inch in height and about half as great in its diameters. It takes its name from a fancied resemblance to a pine cone. It lies between and just anterior to the anterior quadrigeminates.

It is formed as an outgrowth from the inferior portion of the superior walls of the third ventricle. It is composed of two lamina of gray matter, a number of solid cords of glandlike cells, blood vessels, and many small concretions called "brain sand." Many fine, non-medullated nerve fibers, probably sympathetic, and derived from the superior cervical

ganglion, branch freely among the nervous matter and the glandular tissue.

The peduncles of the gland carry fibers, probably passing in both directions, to the nucleus habenulæ, the anterior nucleus of the thalamus, and perhaps other nuclei.

The pineal gland is rarely diseased; when it becomes subject to tumors (sarcòmatous, fibroid, possibly adenoid) or an excessive accumulation of the brain sand, or becomes degenerated or injured through the disease of neighboring structures, no symptoms referable to the gland are present.

Experimental stimulation of the gland, and the experimental injection of its extract into the blood of other animals, produces no results.

This structure is reminiscent of the middle eye of certain lower forms. In certain reptiles and amphibia it is functional; in others rudimentary retina, lens and nerve fibers are demonstrated.

CHAPTER XVI

THE GANGLIONAR CENTERS OF THE CEREBRUM

Anterior to the midbrain the interbrain lies between the cerebral hemispheres. The interbrain includes the optic thalamus, the corpora mammillaria, corpora geniculata, pineal gland, and most of the third ventricle.

Lateral to the thalamus lie the corpora striata. These bodies are properly a part of the cerebral hemispheres, but for the convenience of discussion they are included in this group.

The ganglia grouped around the base of the brain have been studied for a long time, yet their physiological significance is as poorly understood as is any part of the nervous system. Part of the difficulty in study lies in the fact that it is very difficult to reach them for purposes of experiment without disturbing the cortex or the fiber tracts which relate the cortex to other parts of the nervous system. The location of these ganglia between many tracts, associating the areas of the cortex with one another and with the lower centers, accounts for the fact that so few clinic cases are recorded in which uncomplicated lesions of the corpora striata or the optic thalamus or others of these centers have been found. What experimental and clinical evidence is at hand presents many conflicting and apparently irreconcilable factors. Further study is needed. It is especially desirable that pathological brains should be studied by recent methods of neurological technique, and that such findings should be considered in the light of the symptoms observed before death.

The Optic Thalamus

The optic thalamus includes a number of centers of varying functions and relationships. Nissl described twenty different nuclei in the thalamus of the rabbit. Later authors do not verify all of these. With our present incomplete knowledge of these centers it is wiser to follow their example and discuss the centers in groups, leaving their further differentiation for later investigations.

The thalamus is an ovoid body lying medial from the striate body and lateral and inferior to the third ventricle. It forms part of the lateral wall of this ventricle. The word "thalamus" means "bed," and it is so called because it presents a couchlike prominence into the ventricle. At its posterior end the "pulvinar" forms a swelling, which is so called because it is supposed to resemble the "pillow" of the thalamus, or bed. Beneath the pulvinar are two other swellings, the lateral geniculate body and the median geniculate body. Anteriorly, upon the lateral area of the superior surface of the thalamus appears the anterior tubercle, beneath which lies the anterior nucleus of the thalamus.

The thalamus itself is covered by white and gray matter. The gray matter is continuous with the gray matter lining the ventricles. The white matter is composed of the fibers entering and leaving the thalamus. These make up a sheath for the body, and prolongations from this sheath form various partitions, which are more or less complete, and which divide the inner gray matter into many different centers or nuclei. The gray matter of each thalamus is continuous with that of its fellow beneath the third ventricle.

The nuclei of the thalamus are divided into the following groups: The lateral nucleus, medial nucleus, anterior nucleus, the nucleus of the pulvinar and the nucleus habenulæ.

The Nucleus Habenulæ

This nucleus lies beneath the trigonum habenulæ. It is of interest because of its relation to the rhinencephalon. It receives olfactory impulses by way of the thalamic striæ. Fibers from the peduncles of the pineal gland also enter this nucleus.

The axons of the cells of the nucleus habenulæ pass in part to the pineal gland, but for the most part these fibers make up the fasciculus retroflexus (Meynert's bundle), which passes downward through the tegmentum to the ganglion interpedunculare. From this ganglion the fibers pass to the nuclei of the reticular region, and thence to the motor nuclei of the cranial and spinal nerves. The reflex actions associated with the olfactory impulses are thus, in part, controlled.

The Nucleus of the Anterior Tubercle

This must not be confused with the "anterior nucleus" of older authors. It lies on the anterior portion of the dorsal aspect of the thalamus. It is completely inclosed by white fibers, which are continuous with the stratum zonale of the thalamus. It gives fibers to the corpus albicans by way of the fasciculus thalamo-mammillaris (bundle of Vicq d'Azyr), and receives from it the axons of the cells of the corpora mammillaria (corpora albicantia). Since these bodies receive the fornix fibers, the anterior tubercle of the thalamus brings into functional relationship the thalamus and the hippocampal region. The connections thus secured are functional in the coördination of the olfactory impulses.

The Pulvinar

The pulvinar is a mass of gray matter continuous with the lateral nucleus of the thalamus. It receives about one-

fifth of the optic tract fibers. The axons of the cells of the pulvinar pass for the most part by way of the optic radiations to the cortex of the occipital lobe, but others pass also to the superior quadrigeminate by way of the superior brachium. Others of its fibers pass centripetally in the optic tracts to the retina. Injury of the pulvinar causes homonymous hemianopsia.

The Lateral Nucleus of the Thalamus

This is the largest nucleus of the thalamus. It is divided into a number of smaller nuclei, which may or may not be related in function. The lateral nucleus extends from the anterior portion of the thalamus to the posterior, and should be used to include the nucleus of Luys (thalamic) or the central median nucleus, and the arcuate nucleus. The lateral nucleus fuses with the pulvinar at its posterior region.

The lateral nucleus receives fibers from the following sources:

I. The median fillet terminates in this nucleus. A few of the fillet fibers pass without relay into the optic radiations. The impulses concerned in the appreciation of touch, muscular effort and the common sensations are thus transmitted to the sensori-motor areas of the cortex.

II. The spino-thalamic tract carries to the thalamus the impulses of temperature changes, pain and touch. Part of these fibers also may enter the radiations without relay.

III. Fibers from the medial longitudinal bundle enter the lateral nucleus. These fibers are homologous with the fibers from the posterior horn cells and the cells of the central gray matter of the cord. They transmit to the thalamus the impulses of pain and temperature, and perhaps also of touch.

IV. The fibers of the brachium conjunctivum which failed to stop in the neighborhood of the red nucleus termi-

nate in the thalamus. This represents a step in the indirect sensory conduction path. The viscero-sensory impulses, and those of touch, pain, temperature and muscular effort, are thus transmitted in part. Axons of cells of the red nucleus join the brachium fibers and in part terminate in the lateral nucleus.

V. Descending fibers from the cortex enter the lateral nucleus with the radiations. The functions of these descending fibers are not known.

VI. Fibers from the putamen and the caudate nucleus enter the thalamus, and either immediately or after synapsis with cells of the median or other nuclei of the thalamus, carry impulses to the lateral nucleus.

The lateral nucleus is thus an important relay station in the sensory pathway to the cortex. Its fibers are given off as follows:

I. The chief destination of the fibers is to the cortex of the postcentral convolutions.

II. Fibers pass to the corpora striatum, and to other not very well-studied terminations in the related ganglia of the midbrain, the interbrain, the subthalamic and the hypothalamic regions.

Injury of the optic thalamus of one side causes anesthesia, analgesia and ataxia of the opposite side of the body, chiefly, but to a certain extent on the same side of the body.

The Median Nucleus

The median nucleus of the thalamus lies near the median line. It is continuous by gray matter with its fellow of the opposite side, but it is separated from the other thalamic nuclei by a sheet of white fibers. It is continuous also with the hypothalamic gray matter. The median nucleus receives fibers as follows:

I. The strio-thalamic tract seems to send certain of its fibers, if not its chief bundle, to this nucleus.

II. Descending fibers from the operculum and the frontal lobes terminate in this nucleus.

III. Association fibers from other thalamic nuclei and probably from neighboring gray matter terminate in this nucleus.

The median nucleus seems to be a relay station in the descending as well as in the ascending pathway. The axons of its cells pass to the following destinations, probably:

I. To the cortex of the frontal lobes and the operculum.

II. To other thalamic and neighboring centers.

III. To the descending thalamo-spinal tract. This tract seems to pass with the rubro-spinal tract through the length of the cord, terminating at all levels in the region of the central part of the crescent of gray matter. Probably fibers are given to the motor nuclei of the cranial nerves also.

Phylogenetic Development of the Thalamus

The thalamus is one of the oldest of structures. A structure homologous with the thalamus of the mammal is found in the lowest of vertebrates. The functions are variable in different classes of vertebrates, and this changing of function is doubtless due, as in other parts of the nervous system, to the parallel processes of cephalization and specialization.

In the earlier fishes there is no exact division between the midbrain and the interbrain. The fillets, both medial and lateral, terminate in the undifferentiated tectum mesencephali. In the bony fishes, and in all vertebrates above these, as well as in certain of the lower forms, the thalamus can be distinguished as a separate structure.

The nucleus habenulæ presents the rare history of a nucleus present in a certain degree of development and with certain morphological relationships in the lower vertebrates, retaining its morphological and functional relationships through varying degrees of cephalization and specialization on

the part of the rest of the nervous system, yet itself neither becoming more specialized, nor more complex, nor yet losing place or becoming in any wise reminiscent. From the beginning a center associated with olfactory impulses, and transmitting these to the motor centers, it is found in man performing the same functions in practically the same manner. It is true that its position in the scheme of the physiological relationships is apparently less important in the higher vertebrates than in the lower. Yet even in man there is reason to believe that the reflexes aroused by olfactory impulses are more profound and more efficient than has heretofore been believed.

The nucleus of the anterior tubercle also has a history of comparatively uncephalized and unspecialized existence. It is, and has been, associated with the olfactory impulses and their coördination in modifying the movements of the body.

The pushing forward of the visual associations is of interest in this connection. The termination of the larger part of the optic fibers in the region of the midbrain was followed by the development of collaterals from these fibers which entered the lateral geniculate body. The main fibers of the optic tract to the superior colliculus became less functional and less numerous, while the fibers, once collaterals to the lateral geniculate body, became more and more efficient. Later the same processes have resulted in the formation of yet another termination, in the pulvinar of the thalamus.

The auditory neurons have like relationships. First the lateral fillet terminated in the roof of the midbrain, indifferently. Then the posterior colliculus claimed the greater share of the auditory fibers, and this became the chief center for the coördination of the auditory impulses in the control of the movements of the body. Later the development of the anterior centers resulted in the passing of numbers of fibers and collaterals from the auditory fillet to the median genicu-

late body. This body thus became the most important center in the pathway of the auditory impulses toward the cortex.

The development of the lateral nucleus is yet unknown. In the lower vertebrates the median lemniscus terminates in the thalamus, but nothing is known of a thalamo-cortical tract. In monotremes there is found a well-marked tract from the thalamus to the cortex, carrying cutaneous sensory impulses.

The median nucleus is one of the older nuclei. First being chiefly concerned in the transmission of impulses from the striate bodies to the lower motor centers, it has become one of the important centers for the coördination of complex reactions of a reflex or pseudo-reflex nature.

It should be noted in the case of the thalamus, as in the case of the quadrigeminates and the cerebellum, that the same processes which lead to the function of any organ being superseded by higher centers, lead also to the development of new coördinations, sometimes only distantly related to the older and more general functions.

The place of the thalamic centers in the emotional reactions is a matter of dispute. The median nucleus seems to be concerned in these reactions. Stimulation of the sub-thalamic region in the cat and the dog initiate the movements characteristic of anger. It is not possible to localize the exact center stimulated in such experiments.

The Medial Geniculate Body

The medial geniculate body lies upon the inferior aspect of the thalamus, medially to the lateral geniculate body. It appears to be the terminal ganglion of the central root of the optic tracts. It does receive the fibers of Gudden's commissure, which run with the optic tracts posterior to the chiasma, but which are not functionally related to the visual centers.

The medial geniculate body contains small cells of spindle or fusiform outline, with few small dendrites. It does not

present a laminated appearance on section, and appears to be of simple structure.

It receives fibers as follows:

I. Axons of cells of the auditory nuclei, the superior olivary nuclei, and the nuclei of the trapezoid body reach this body by way of the lateral fillet. In this way the impulses concerned in consciousness of hearing are carried to the cortex.

II. Axons of cells of the inferior quadrigeminates pass by way of the inferior brachium to this body. In this way also some of the auditory impulses are carried.

III. Axons of the lateral geniculate body of the opposite side, and probably of the corpus striatum of the opposite side, by way of part of the lenticular loop fibers, pass by way of Gudden's commissure to each lateral geniculate body.

IV. Axons of cells in the centers of the thalamus probably end in the lateral geniculate body, bringing into coördinate function these centers.

V. Axons of cells of the cortex of the auditory areas of the temporal lobes pass by way of the acustic radiation to the lateral geniculate body. Impulses carried by this path seem to be essential to the maintenance of normal nutritive conditions of the auditory structures, particularly the cochlea.

The axons of the cells of the median geniculate body pass to the following structures:

I. Axons pass in the acustic radiations to the cerebral cortex of the first and second temporal convolutions, the so-called "auditory area." Thus the impulses concerned in conscious hearing are carried.

II. Axons pass to the inferior quadrigeminates by way of the inferior brachium. The descending cortical impulses are thus transmitted peripherally in part.

III. Axons descend along the path of the lateral fillet.

In this way also the descending impulses are transmitted peripherally.

IV. Axons pass by way of Gudden's commissure to the opposite median geniculate body, and perhaps to the striate body of the opposite side.

V. Axons pass to the thalamic nuclei of related function.

VI. Axons pass to the red nucleus and related ganglia.

The medial geniculate bodies are not subject to disease, but are affected by abnormal processes of neighboring structures. Injury of either median geniculate body produces deafness of both ears — chiefly of the opposite side, according to some authors, but equally, according to others. Usually the injury of either is associated with injury of the other.

Stimulation of the median geniculate bodies of the cat causes movements of the eyes and the ears, provided the inferior connections are not injured. The presence or absence of the cortex seems to have no effect upon the results of stimulation of these bodies under the conditions of our experiments.

The Lateral Geniculate Body

This is a swelling or protuberance upon the inferior and lateral aspect of the thalamus. It is phylogenetically ancient, being found in the lower fishes, but it seems of very little importance below mammals. This nucleus contains large, multipolar, pigmented nerve cells, whose dendrites branch freely. The nerve fibers which enter it pass through its substance in sheets or layers, and thus give the nucleus a striated appearance something like that of the anterior quadrigeminate body. The lateral geniculate body receives fibers from the following sources:

I. About eighty per cent. of the optic-tract fibers terminate in this nucleus and the pulvinar. In man, about one-half of these fibers are from the homo-lateral retina, and about

half from the contra-lateral retina. In lower vertebrates the number of crossed fibers is much greater; in animals whose eyes are situated very far at the side, so that the two fields of vision do not overlap, the lateral geniculate body receives only contra-lateral retinal fibers.

II. Fibers from the pulvinar and perhaps other thalamic centers bring the activity of the nuclei associated with sight sensations into coördinate function.

III. Descending fibers from the occipital cortex terminate among the cells of the geniculate body. The impulses thus derived seem in some way to be essential to the nutrition of the ocular structures, and especially of the retina, but the manner of their activity is not known.

The axons of the cells of the lateral geniculate body pass to the following destinations:

I. Axons pass as part of the optic radiation to the visual area of the occipital cortex. In this way the impulses concerned in conscious vision are carried.

II. Axons pass by way of the superior brachium to the anterior quadrigeminate body. The impulses thus carried are concerned in the coördination of the movements and the nutrition of the eye and its associated structures.

III. Axons enter the pulvinar and perhaps other thalamic nuclei. The activity of the related centers concerned in vision is thus coördinated.

IV. Axons pass to the red nucleus and related ganglia.

The lateral geniculate body is not itself very subject to disease, but injury of neighboring parts of the brain often affect it. When it is injured, bilateral homonymous hemianopsia is produced.

Experimental stimulation of the body after ablation of the midbrain produces no effects. With an intact midbrain stimulation of the lateral geniculate of the cat causes movements of both the eyes and the ears of both sides. Ablation

of the cortex does not seem to affect the movements resulting from this stimulation.

The Corpora Mammillaria

These bodies lie in front of the posterior perforated space and behind the optic commissure. Each corpus is the size of half a small pea, and about the same shape.

The structure of this body is rather more complex than at first appears. (Fig. 64.) Its outer layer is composed of white matter, the descending fornix fibers. These pass around the lateral surface of the body, beneath it, and upward on its median aspect. As the fibers thus encircle the body they pass into its substance, a few at a time, until at the medial upper part of the body all the encirling fibers have entered the inner gray matter. The entering fibers, after plunging into the gray matter, form a series of whirls, which inclose within them a number of fairly large multipolar cells with long but not very freely branching dendrites. The axons of these cells pass with the entering fibers into the deeper gray matter of the corpus. The central portion of the median nucleus is composed of gray matter, together with the fibers terminating and originating therein. The cells of this nucleus are rather smaller than those just mentioned, their dendrites are shorter, and they branch more freely. The entering fibers break up into a number of fibrillæ, which form large baskets around the intrinsic cells. Each fiber may enter into the formation of several baskets, and each basket may receive fibrillæ from several fibers. (I have found four fibrillæ entering one basket, and one fiber giving fibrillæ to two baskets, in several instances.) (Fig. 65.)

These baskets are much larger than the bodies of the cells which they inclose, and are composed of an extremely fine network, so that in sections one often finds part of the network with no cell body apparent within it. This gives

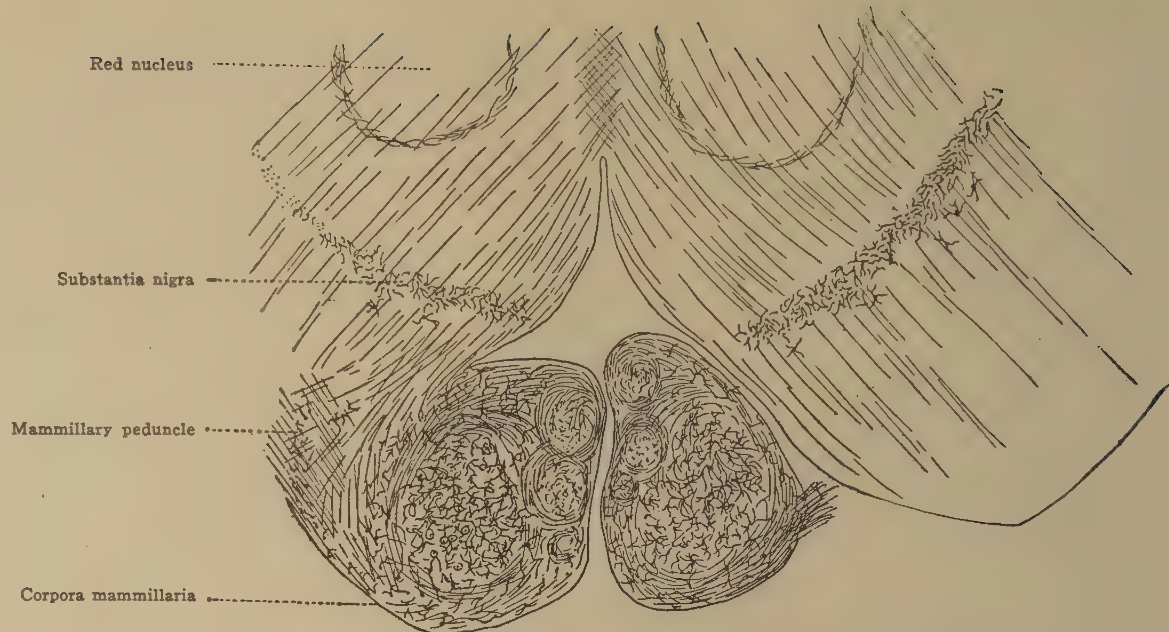


Fig. 64. Section through corpora mammillaria, adult woman. 10 diameters.

something the appearance of the olfactory glomeruli to the sections. These baskets are not arranged in any apparent order, as are the olfactory glomeruli, but lie scattered all over the central portion of the median nucleus.

The axons of the cells of the median nucleus form the principal mammillary fasciculus. The fibers of this bundle pass upward and bifurcate. One branch enters the anterior

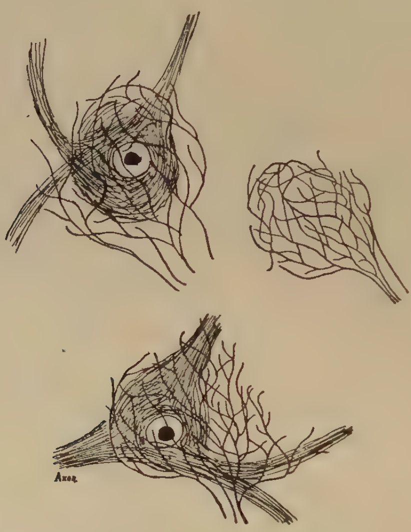


Fig. 65. Cells from corpora mammillaria. 800 diameters.

nucleus of the thalamus. This is the thalamo-mammillary bundle (bundle of Vicq d'Azyr). Probably some fibers, axons of the thalamic cells, pass downward with this bundle into the corpora. The other branch, the pedunculo-mammillary bundle, passes backward toward the tegmentum. It runs near the median longitudinal bundle through the tegmentum, and gives collaterals or axons to the substantia nigra and the red nucleus. Both branches of the principal mammillary bundle are concerned in carrying impulses which relate the bodily movements in answer to the olfactory impulses.

The lateral nucleus of the corpora mammillaria is smaller. It receives a part of the descending fornix fibers. These form synapses with multipolar cells of median size, with rather long but not very freely branching dendrites. The axons of some of these cells pass with the remaining fornix fibers to the median nucleus. Other axons enter the pedunculo-mammillary bundle as its basilar portion, and pass with it through the tegmentum. These fibers seem to terminate in the central gray matter of the midbrain, and through this are brought into relationship with the viscero-motor nuclei of the medulla. Perhaps the somatic cranial nerve nuclei are also under the influence of the impulses carried by this tract, and indirectly the centers of the cord may also be affected thereby.

The Red Nucleus

The red nucleus, or nucleus ruber (nucleus of Stilling), lies beneath the aqueduct and the third ventricle. It receives its name from the fact that it is unusually freely supplied with blood, so that in the fresh specimen it presents a distinctly reddish appearance. This nucleus contains extremely large cells, whose dendrites attain great length and branch very freely. These cells are inclosed by the branching incoming axons and collaterals, and by their own dendritic and collateral branchings, as well as by the axons of the Golgi cells of Type II.

The red nucleus receives fibers from the following sources:

I. From the nucleus dentatum by way of the brachium conjunctivum.

II. From the lateral and the medial fillet.

III. Descending fibers from the cerebral cortex, chiefly of the frontal, parietal and occipital regions.

IV. Association fibers from the neighboring gray mat-

ter, the striate bodies and the thalamus, especially the median nucleus of the thalamus.

The axons of the cells of the red nucleus pass as follows:

I. To the nucleus dentatus by way of the brachium conjunctivum.

II. To the thalamus, and to the cerebral cortex of the somesthetic area.

III. To the neighboring gray matter.

IV. To the motor nuclei of the cranial nerves, and to the centers both visceral and somatic in the pons, medulla and midbrain, and to the center of the gray crescent of the spinal cord of all levels, by way of the rubro-spinal tract.

The red nucleus must be considered as one of the centers for the control of the instinctive and emotional reactions.

The Infundibular Structures

The tuber cinereum lies immediately posterior to the optic chiasma. Its gray surface is directly continuous with the posterior perforated space of the interpeduncular region. Its protrusion beyond the rest of the gray matter is due to the outgrowth of the infundibulum.

The infundibulum is a tube, an outgrowth from the inferior aspect of the third ventricle. It passes obliquely downward into the hypophesis cerebri, or pituitary body.

The pituitary body, or hypophysis cerebri, is found in all vertebrates, but very much larger in the lower types. The posterior lobe has been studied thoroughly by Berkeley. He describes three chief varieties of cells, large and small pyramidal, very much like those of other parts of the nervous system, and smaller cells with freely-branching dendrites, and three or four small, slender axons, which terminate in forming synapses with other cells of the same structure. All three

classes of cells send axons toward the infundibulum, but neither Berkeley nor any one else has described these axons as terminating in other parts of the nervous system. Gland cells are also found in the posterior lobe.

The anterior lobe of the pituitary body is not of nervous origin. It is developed as an outgrowth from the pharyngeal region, comes into anatomical relationship with the posterior lobe, and remains in that place. Both lobes are very freely supplied with blood vessels, which are plentifully innervated by sympathetic fibers. The glandular tissues of the anterior lobe are supplied with sympathetic fibers, which have a termination which suggests that they are secretory in function.

The pituitary body may be diseased, but not frequently. It may be hypertrophied, atrophied, or subject to tumors. When it is diseased the patient may suffer from no symptoms referable to the gland, or he may suffer a peculiar overgrowth of certain bones, as in the disease called "acromegalia."

Experimental stimulation of the gland gives no effects. Extracts from it may affect blood pressure. The presence of colloid material in the acini suggests a relationship with the thyroid gland.

The Corpus Striatum

The corpus striatum is so called from its being penetrated by layers of the white fibers, which give its gray matter a striated appearance.

It is a body of about the shape and size of a hen's egg. It measures about two and a half inches in its antero-posterior diameter, and an inch and a half or an inch and a quarter in its other diameters.

It is divided into two divisions by the internal capsule, the caudate nucleus and the lenticular nucleus.

The Caudate Nucleus

The caudate nucleus forms a part of the floor of the lateral part of the lateral ventricle. Its head, or broad part, is directed anteriorly. It is continuous wth the anterior perforated space. The tail terminates in the nucleus amygdalæ.

The caudate nucleus and the lenticular nucleus are connected by bands of fibers both at their anterior and their posterior extremities. The presence of considerable numbers of fibers, which pass from the caudate nucleus to the lenticular nucleus, together with the position of the nucleus in the floor of the ventricle, renders probable the view that the caudate nucleus is derived from the epistratum in fishes. The caudate nucleus still receives many olfactory impulses, as is to be expected when one remembers that its primitive function is concerned in olfactory coördinations. The presence of the optic radiation and the cortical structures is associated with increasing complexity of relations among the nuclei of the striate and thalamic bodies.

The Nucleus Lentiformis

The nucleus lentiformis, or the lenticular nucleus, is composed of a lens-shaped mass of gray matter, crossed by many sheets of thin white matter. It is thus divided into three zones, of which the outer is called the putamen. The two inner masses are rather less well supplied with blood, contain less pigment, and are thus less paler than the other gray masses. They are called the globus pallidus for this reason.

The putamen is characterized by the great size of its multipolar cells and by the great length and irregularity of their dendrites. Its gray matter is continuous with that of the caudate nucleus anteriorly. It both gives and receives fibers from the caudate nucleus and from the globus pallidus.

The globus pallidus is composed of two, three or more masses of gray matter. In this part of the brain the circulation is less plentiful than in other parts of the gray matter. The cells of the globus pallidus are smaller and less irregular in outline than in the putamen. The globus pallidus is less well developed in the lower vertebrates than are the other masses composing the corpora striata.

The connections of the different parts of the corpora striata are either very much alike or they have not been well worked out; for this reason it seems best at present to give them in one group.

Each corpus striatum receives fibers from the following sources:

I. Olfactory axons, of the second or higher orders, terminate in the caudate nucleus and the putamen.

II. Fibers from the thalamus, midbrain, and the sensory nuclei of the second and higher orders, enter the lenticular nucleus probably in all of its parts, to a certain extent.

III. Descending fibers from all parts of the cortex of the same hemisphere enter the striatum.

IV. Collaterals from the descending cortical fibers enter the putamen, and probably the globosus and the caudate nucleus. This is most conspicuously seen in descending pyramidal fibers from the precentral convolution.

V. Fibers from the thalamus and the striatum of the opposite side enter the striatum.

VI. Fibers from the red nucleus probably terminate in the inner section of the pallidus. Such fibers would make a part of the indirect sensory pathway.

The fibers leave the striatum to pass to the following destinations:

I. Fibers pass in the strio-thalamic bundles to the thalamus of the same side.

II. Fibers pass to the thalamus of the opposite side.

III. Fibers pass to the hypothalamic centers and to the red nucleus and substantia nigra of the opposite side, and also to the same side.

IV. Fibers pass upward to the cerebral cortex of all areas.

The stimulation of the various areas of the corpora striata gives no recognizable results.

Diseases of the striatum are almost certain to affect the internal capsule, and to produce the paralysis due to this injury. Injury of the striatum without injury to the capsule may produce no symptoms, or may give rise to indefinite and variable symptoms, so that no conclusions can be drawn therefrom, nor can the diagnosis of the lesion of the striate body alone be made antemortem.

The Amygdaloid Nucleus

This nucleus is produced by a thickening of the gray matter of the cortical infolding associated with the hippocampus major. It thus protrudes upon the surface of the inferior horn of the lateral ventricle as an almond-shaped swelling. It is of interest in its position in phylogeny as one of the very earliest cortical developments, and it is in all vertebrates one of the chief cortical centers of the sense of smell. The end of the tail of the caudate nucleus is continuous with its gray matter.

It receives fibers from the olfactory cells of the second and higher orders, and perhaps from neighboring areas of the cortex. A few fibers of long association tracts bring this area into relationship with the other cortical areas in mammals. It sends the axons of its cells to the following destinations:

I. To the nucleus habenulæ by the stria medullaris, or tractus olfacto-habenularis;

II. To the hypothalamus by way of the tænia semicircularis, or lateral olfacto-hypothalamic tract;

III. To the hippocampus major by way of the subcallosal gyrus and the fimbriæ;

IV. To other areas of the cortex by way of the long and the short association tracts;

V. To the opposite side of the brain by way of the several commissures, either directly or indirectly.

CHAPTER XVII

THE CORTICAL CENTERS

The centers concerned in the immediate control of the various functions of the body have been discussed. It is evident that among these centers there are to be found many variations in complexity. From the simplest reflex actions performed through the agency of the spinal arc to the almost infinite complexity of the higher centers there appear all grades of structural variety, with a concomitant functional variety of neuron relationship. But in the cortical centers there is found a degree of complexity, both of structure and of function, which renders the centers already described almost simple by contrast. It is not that the cortical centers present more varieties of structure — indeed, the structure of the cortex appears very simple compared with the structure of the olfactory tracts, for example — but this simple structure is presented upon so broad a plane, and the inter-central relationships are so well developed, that the number of variations in reaction which might follow any given sensory stimulation is beyond imagination.

The cerebral hemispheres are covered by a thin and fairly regular layer of gray matter. This layer is called the cerebral cortex. It varies slightly in structure and in thickness in different areas of the cortex, though these variations are not nearly so profound as one would expect when the extreme variations in the functions of the different areas are considered. In thickness there is also some variation. About one-

Fig. 66. Spindle cells from first layers of cerebral cortex.
Kitten, half grown. 175 diameters.

Fig. 67. Section across cerebral gyrus, half-grown kitten. 25 diameters.

third to one-sixth of an inch is the usual thickness of the cortex.

During embryonic development the nerve cells of the cortex grow with extreme rapidity. The increase in the area of the gray matter is thus very great, while the associated growth of the white matter, the core of the hemisphere, is comparatively small. As a result of this lack of relative development the gray matter is thrown into a series of folds, called convolutions or sulci. In this way the cortical area becomes comparatively of great extent.

The structure of the cortex offers almost inexhaustible facilities for association of neuronic activities. The arrangement of cells and fibers varies somewhat in the different areas of the brain, though the chief factors are everywhere to be found. The classification of the cortical cells into seven layers seems to be accepted.

I. The outer layer of cells is covered over and separated from the pia matter only by a layer of neuroglia, which penetrates and supports the nerve cells. These cells are of small size, stellate or spindle-shaped in form, and are either of the amacrine type, of the Golgi Type II, or of similar structure. Among them are found cells which seem to have two or three processes resembling axons. (Figs. 66, 67.) These branch in a T-shaped manner, giving collaterals freely to neighboring cells. This layer of cells receives the incoming fibers from the lower centers and from other areas of the cortex, the collaterals from the axons of the cells of the deeper layers, and the axons of the reversed pyramids. The axons of the cells are all short and do not leave the layer within which they are found. This layer is found more highly developed among races and individuals of high attainments and civilization. It seems that it is the place of most exact coördinations. Facts of clinical evidence indicate that it is in this area that consciousness primarily is affected.

The second layer includes the small pyramidal cells, rather closely placed. A few polymorphic cells lie among the pyramids. The apical dendrites of these cells pass toward the periphery of the cortex, and branch freely among the spindle cells of the outer layer. The basal dendrites pass horizontally and branch freely among the other cells of the same layer. The axons of the small pyramidal cells descend to the deeper layers. They are of small diameter, and probably rarely leave the gray matter. These axons give off collaterals, which pass horizontally for a time, giving off branches which form synapses with other cells of the same layer. These collaterals and their branches pass toward the periphery and enter into synaptic relations with the cells of the outer layer. The descending axons of the cells form synapses with the cells of the deeper layers.

The third layer resembles the second, and is included with it as the second layer of the older texts. The pyramidal cells are nearly twice the diameter of the small pyramids, and they are pushed further apart by the greater complexity of their dendritic branchings.

The fourth layer is the layer of large pyramidal cells. These are of great size, especially in the motor areas of the cortex. Their apical dendrites pass into the outer layers, and branch freely among the cells of these layers. Their basal dendrites branch freely in the same layer. The axons and collaterals of the small and medium pyramidal cells form a network of interlacing dendrites around the bodies and among the dendrites of the large pyramids. The horizontal fibers of these dendrites and axons give the appearance called the line of Baillarger. The axons of the large pyramids enter the white matter.

The fifth layer includes the stellate or polymorphic cells in variable numbers. These cells are scarcely to be found in motor areas, but are well marked in the auditory and visual

areas. They are found in the post-central convolutions. The dendrites of these cells branch freely, but are not very long. Their axons pass horizontally within the same layer. Either the axons themselves or their collaterals pass to the outer cell layer to branch among the stellate and spindle-shaped cells.

The sixth layer is the inner layer of large pyramids. In the motor areas these are of very great size. It includes many cells of the Golgi Type II, as well as polymorphic cells.

Fig. 68. Pyramidal cells, occipital lobe, new born baby. 175 diameters.

The giant cells of this layer are characteristic of the motor area. These, as well as the large pyramids of the fourth layer, are found degenerated in amyotrophic lateral sclerosis. Their place as the origin of the pyramidal tracts is thus demonstrated. (Figs. 68, 69, 70.)

All of the large pyramidal cells contain great masses of tigroid substance (Nissl), and these masses are found absent after long-continued overwork of the cells, as after epileptic attacks or convulsions.

The seventh layer includes polymorphic cells, chiefly of the spindle variety. (Figs. 71, 72.) The cells have several

Fig. 70. Pyramidal cell from cortex, half-grown kitten.

Fig. 72. Hippocampus, half-grown kitten. 10 diameters.

Fig. 69. Pyramidal cells from temporal lobe, adult woman. 175 diameters.

Fig. 71. Polymorphic cells from seventh layer of occipital lobe, new-born baby. 190 diameters.

dendrites, which are often very long and may or may not branch very freely. Their axons enter the white matter and pass to adjacent or distant areas of the cortex. Some pass toward the outer layer of the cortex. This layer includes many cells of the Golgi Type II and a few inverted pyramids. The axons of the latter pass into the outer layer of the cortex, giving collaterals to all layers in passing.

The different areas of the cerebral cortex are occupied by centers for the performance of different functions. The factors concerned in the primary localizations are not well understood. In the cortex of lower mammals very little differentiation of structure is to be found. With increasing development of any cortical function the centers concerned in that function show increasing complexity and greater peculiarities of structure. It seems that the assumption of any function by any cortical area is associated with such a change in the structure of that area as best fits it for the performance of those duties. It is apparent that the assumption of any particular duty by any particular cortical center must be due to one or several conditions. The certain area most accessible to the sensory impulses concerned in the control of any specific function would, other things being equal, assume most readily those duties. On the other hand, the areas of the cortex in the lower mammals, while they appear alike throughout, may be found to possess variations which render them more fit for the performance of one duty than another. The fact that among the various classes of mammals the same arrangement of centers upon the cortex is presented is evidence that the structural adaptations to the performance of the different functions are an essential part of the lower mammalian, and probably also of the vertebrate, morphology.

In the development of the cortical centers the relation between structure and function is shown. The structure seems

to be essential to the assumption of duties; the assumption of the duties leads to the development of the structure better adapted to the performance of those duties. The performance of function and the development of structure occur together. Both together make the greater efficiency, which is the reply of living creatures to the environmental demands.

The areas which are recognized as possessing specific functions do not include the entire cortex. Each specific function is surrounded by an area of cells which, in the lower mammals, seem to have no function, and in man are not known to have specific functions. There are large expanses of cortex which appear to contain no centers and to be non-functional. The indifferent areas are of less extent in mammals of higher development.

The area surrounding the center for any specific function has been called the "psychic" center for that function. This term is very unfortunate. In the first place, the term "psychic" gives the impression of consciousness. It is not known that there is any more mentality or consciousness concerned in the activity of the "psychic" areas than in the activity of the other cortical areas. It is unfortunate to employ words of philosophical significance to physiological phenomena. The word "psychic" has its own significance; it is already a useful term, and to apply it to a structural area adds unnecessary confusion and lessens its proper value. For these reasons I have ventured to employ the term "overflow" in this connection. The "overflow" of any center is the adjacent cortical area whose cells are subject to stimulation by that center. No psychological significance is attached to the word, and it must be remembered that the term refers to the structural relationship only. It is yet to be determined what relationship exists between the activity of the cortical areas and the phenomena of consciousness.

The cortical centers are most exactly explained by considering the sensory centers or areas first.

The Common Sensory Centers

The common sensory area includes the posterior wall of the central sulcus, the anterior half of the posterior central gyrus (ascending parietal convolution), and the adjacent part of the paracentral lobule. This area is divided into smaller areas, which are the centers of the different bodily areas. All epicritic and a part of the protopathic sensations are consciously appreciated by means of the activity of these areas. Disease of this area causes loss of sensation of those parts of the body in relationship with the affected centers. In locomotor ataxia the area is found degenerated after the method of Nissl.

The centers for common sensation receive impulses as follows:

I. Epicritic sensations are carried from the lower part of the body and the lower limbs by way of the sensory nerves, sensory ganglia, posterior roots, fasciculus gracilis, nucleus gracilis, the median fillet (decussating), the lateral nucleus of the thalamus, the thalamic radiations to the cerebral cortex.

Certain of the impulses of this class seem to be carried as described to the nucleus gracilis, from this point by way of the restiform body to the cortex of the superior vermis of the cerebellum, thence to the nucleus dentatus, then by way of the brachium conjunctivum to the red nucleus, then to the optic thalamus, probably the globus pallidus, and the cerebral cortex.

II. Epicritic sensations are carried from the upper limbs, the upper part of the body, including the neck, as high as the lower line of the mandible, by way of the sensory nerves and ganglia, the posterior roots, the fasciculus cuneatus, the nucleus cuneatus, the median fillet, the lateral nucleus of the

thalamus, the thalamic radiations and the cortex of the opposite side. The crossing occurs at the decussation of the fillet, in the medulla.

III. Protopathic sensations from the entire body, and probably some of the visceral sensations, are carried by way of the sensory nerves and ganglia, the posterior roots, the cells of the dorsal nucleus or the posterior horn, thence to the opposite side into the spino-thalamic tract, to the lateral nucleus of the thalamus, and to the cortex.

IV. Visceral and perhaps also protopathic sensations are carried by way of the sensory nerves and ganglia, the posterior roots, the cells of the dorsal nucleus (Clarke's column), thence to the lateral ascending cerebellar tract of the same side, and through the restiform body to the cortex of the superior vermis of the cerebellum; from the cerebellar cortex the impulses are carried to the nucleus dentatus, thence by the brachium conjunctivum to the red nucleus, thence to the thalamus, the caudate nucleus, and the cerebral cortex.

V. Similar impulses are carried by the same path to the dorsal nucleus of the cord, thence by way of the ascending cerebellar tract and the brachium conjunctivum to the cortex of the superior vermis of the cerebellum, thence, as in the case of IV, to the cerebral cortex.

VI. The cranial nerves of common sensation send impulses by way of their nuclei of insertion to the cerebellum, and thence by the pathway already described to the cerebral cortex, and they send impulses by way of the median fillet to the lateral nucleus of the thalamus, and thence to the cerebral cortex by the thalamic radiations.

VII. Impulses from corresponding areas of the opposite side of the brain reach each area of common sensation.

VIII. Impulses from adjacent cortical areas, and from distant cortical areas, reach the areas for common sensation.

The area for common sensation sends impulses as follows:

I. Impulses are carried by short fibers to the sensory overflow, in which probably memories of the body sensations are stored.

II. Impulses pass to the motor areas in the anterior wall of the central sulcus, and in the adjacent part of the paracentral lobule.

III. Impulses pass to the lower centers, the thalamus, the corpora striata, the smaller basal ganglia.

IV. Impulses pass to corresponding areas in the opposite hemisphere, and to other parts of the same hemisphere, but chiefly to the frontal lobes.

This area, then, receives all common sensations from the body, the epicritic sensations by a pathway of direct and with few relay stations, the protopathic and visceral by a longer, indirect pathway, with many interposed neuron systems. The impulses thus received are transmitted to the basal ganglia, and are concerned in modifying the instinctive reactions, and to the frontal lobes, especially the left, in which the impulses concerned in the ideas of personality, of one's own position in the midst of his environment, are coördinated.

The Auditory Center

The area concerned in hearing is placed in the first and second temporal gyri. This area receives impulses as follows:

I. Impulses aroused by the stimulation of the hair cells of the organ of Corti in the middle ear are carried by the dendrites of the auditory cells, the ganglion spirale, the cochlear portion of the auditory nerve to the nuclei of termination of the auditory nerve (the lateral and the median nuclei), thence by way of the trapezoid body, decussating, into the lateral fillet; after an uncertain number of relays in the

nucleus of the trapezoid body, the superior olivary nucleus and the accessory nuclei of the superior olivary body, the impulses are carried by the lateral fillet to the inferior colliculus, thence by the inferior brachium, and also by way of the fillet, to the internal geniculate body, the acustic radiations, and the cortex of the first and second gyri of the temporal lobe.

II. The areas for hearing receive impulses from corresponding areas of the opposite hemisphere; from neighboring and distant areas of the same hemisphere.

The acustic area, or center, sends impulses as follows:

I. By way of the acustic radiations, the internal geniculate body, the inferior brachium and the inferior quadrigeminates, the descending fibers of the lateral fillet, thence by the nuclei of insertion of the auditory nerves, the nuclei of the motor nerves for the auditory muscles, the vaso-motor centers for the internal ear, to the cochlea and the structures directly or indirectly concerned in hearing.

II. The impulses initiated by the activity of the cells of the acustic area are carried by short association fibers to the auditory overflow, in which are probably located the areas for associative memories of things heard.

III. Impulses are carried by long association tracts to the distant areas of the cortex, of the same hemisphere, and to the corresponding areas of the opposite hemisphere.

The Visual Centers

The cortical center for the consciousness of seeing occupies the cuneus and lingual gyrus. The visual overflow includes a rather extensive neighboring area of the cortex; the exact limits of this area are not well known at present. The cuneus and the lingual gyrus seem to receive the impulses initiated in the retina, and consciousness is affected by the functional activity of the cortical cells of this area. The stim-

ulation of these cells causes the stimulation of the neighboring cells of the visual overflow, and the activity of these cells is probably concerned in the appreciation of the significance of things seen.

The visual center receives impulses from the following sources:

I. The visual center of each hemisphere receives the impulses initiated in the yellow spot of the retinæ of both eyes.

II. The impulses initiated in the homolateral halves of both retinæ reach the visual center. These impulses, as well as those of I, are carried as follows: The light affects first the rods and cones. The stimulation of these causes the stimulation of the bipolar cells of the retina, which in turn stimulate the ganglionic cells of the retina. The axons of the ganglionic cells make up the optic nerves. These pass backward to the optic chiasma. Here the nasal halves of both retinæ decussate, while the temporal halves persist upon the same side. The fibers, the same axons of the ganglionic cells, are called optic tracts posterior to the chiasma. The term tract properly belongs to the bundles of axons of the ganglionic cells through their entire extent. These tracts give off a bundle which passes to the anterior quadrigeminates, in which we have at present no interest. The most of the fibers of the optic tract enter the lateral geniculate body and the pulvinar of the thalamus. The latter represents the higher development. There are certain relay stations in the geniculate body and the thalamus, no one can tell how many, and the relationship between the thalamus and geniculate body is very intimate. The cells of these bodies send axons in the optic radiations to the cortex of the cuneus and the lingual gyrus.

III. The optic center receives impulses from the corresponding areas of the opposite hemisphere, and from practically all parts of the same hemisphere.

The optic center sends out impulses as follows:

I. Impulses pass downward, following the ascending path of the sensory impulses, by way of the optic radiations, the pulvinar and geniculate body, the optic tracts, to the retinæ. These impulses are apparently concerned in some way with the nutrition of the retinæ. Impulses from the geniculate body, originating in the cortex as in the case just mentioned, pass to the anterior quadrigeminate by way of the superior brachium. Probably the coördination of the eye structures in answer to the needs of conscious seeing are thus secured.

II. Impulses pass by short association fibers into the visual overflow.

III. Impulses pass by long association fibers to the opposite visual center, and to other parts of the same hemisphere.

IV. Impulses are carried to the central ganglia. The relationship of these fibers has not been sufficiently studied.

Olfactory and Gustatory Centers

The cortical areas for taste have not been outlined with any degree of certainty. The few facts which are known in this connection seem to indicate that taste and smell have cortical areas which are very closely related, if not, indeed, actually identical. For this reason the olfactory areas, which are fairly well known, will be described, and the gustatory left with the rather unsatisfactory statement that the description of one probably applies, with at least a fair degree of accuracy, to the other.

The uncus hippocampi probably is to be considered the chief center for smell. Either the fusiform gyrus or the cingulum may be considered the center for taste, though all of these areas are included in the rhinencephalon. Since the olfactory impulses secured the very earliest cortical represen-

tation, they are to be held worthy the respect due to ancient lineage. Phylogenetically the oldest, the olfactory centers have been subjected to much pressure from the developing centers for other functions. The olfactory areas have been pushed aside, and distorted, and compelled to new connections, and to constant rearrangements in order that they might remain adapted to the changing conditions caused by the constant and almost unending processes of cephalization. In this way the centers concerned in smell and to a certain extent in taste have become of so great structural complexity.

The olfactory centers have been described already in a previous chapter. The connections of the uncus and the cingulum may be very briefly given.

The olfactory and gustatory areas receive impulses from the following centers:

I. Impulses from the olfactory membrane pass by way of the olfactory nerves, the olfactory glomeruli, the mitral cells, and their axons as they make up the olfactory tracts to the olfactory areas at the base of the brain. Here the impulses are carried by three or four different roots to the uncus hippocampi, the inferior gyrus of the temporal lobe, the amygdaloid nucleus, and various parts of the limbic lobe. The uncus seems to be the chief center for consciousness of smell.

II. Impulses concerned in taste are carried by way of the sensory nuclei of the fifth, seventh and ninth cranial nerves, the median fillet, the lateral nucleus of the thalamus, perhaps the caudate nucleus and the globus pallidus, to the taste centers, probably in the gyrus cinguli or the fusiform gyrus, with other connections in the neighboring parts of the rhinencephalon.

III. Impulses of touch, temperature, and probably of pain, are transmitted from the somesthetic areas to the centers for both taste and smell. In this manner the taste and the smell are both subject to modification by the other sen-

sory impulses. It is also true that the temperature and touch changes modify the circulation and other local conditions of the receptive membranes.

IV. All parts of the rhinencephalon are intimately associated by small nerve tracts of association.

V. The olfactory area receives association fibers from nearly all of the lower centers of the cerebrum. The relationship which the sense of smell bears to the instinctive and emotional reactions is thus, in part, secured.

VI. The olfactory area receives very few association fibers from other parts of the cortex. The relationship between the smell of things and the sight or the sounds of things is thus rather scanty.

The olfactory area sends impulses to other centers as follows:

I. Impulses from the olfactory area are carried to the frontal lobes, and to a less extent to the parietal lobes, by association tracts.

II. Impulses pass downward, following the ascending path, to be distributed finally to the olfactory lobes, and perhaps the impulses thus carried may be transmitted by descending fibers to the olfactory membrane.

III. Impulses pass to the nucleus habenulæ, from which they are carried by the fasciculus retroflexus (Meynert's) to the interpeduncular ganglion, and probably to the motor nuclei of the cranial and certain spinal motor nerves. Thus the olfactory impulses are able to initiate skeletal movements.

IV. Impulses are carried by way of the fornix to the corpora mammillaria. From these bodies fibers pass to the thalamus, and to the gray matter around the cerebral aqueduct. The latter pathway transmits the impulses to the nuclei of the viscero-motor cranial, and perhaps certain spinal nerves. Thus impulses of smell are able to modify visceral activities.

V. Impulses from the different parts of the rhinen-

cephalon are carried by many small nerve tracts to practically all of the nuclei of the corpora striata, the thalamus, the sub and hypothalamic centers, and the substantia nigra, red nucleus, etc. In this way the impulses aroused through odors are able to affect the emotional and instinctive actions.

VI. Impulses from the rhinencephalon are carried to the other parts of the cortex. In this way the information brought through the olfactory tracts may be correlated with the information brought by other sensory tracts. This relationship is much less exact, so far as consciousness is concerned, than are the relationships between the other senses. On the other hand, the impulses aroused by odors, by the very fact of their poor relationships, are in themselves very efficient in arousing efferent impulses.

The Stereognostic Center

The center concerned in the appreciation of things as having three dimensions, the stereognostic center, lies in the superior parietal lobule and the precuneus. This area is continuous, posteriorly, with the visual overflow, and anteriorly with the somesthetic overflow. The stereognostic image is primarily a function of touch, and in part also of muscular effort. The application of this knowledge to the interpretation of visual images affords a very important addition to the value of sight in adding to the knowledge the individual has of his more extended environment.

The stereognostic center receives impulses as follows:

I. Chiefly, the center is affected by impulses from the somesthetic centers.

II. An important stream of impulses is carried from the visual overflow.

III. Impulses from the opposite hemisphere are transmitted to this area, and impulses from other centers of the same hemisphere are sent to the stereognostic center.

Impulses from the cells of the stereognostic center are carried to the following destinations:

I. Impulses are sent to the motor centers. The efficiency of the volitional coördinations is thus increased.

II. Impulses are sent to the visual, and, to a slight extent, to the auditory, overflow. The appreciation of space and of extension in three directions is thus added to the psychical content of the auditory and visual images.

III. Impulses are sent to other parts of the cortex, and to the homologous center of the opposite hemisphere.

Only a few records are found of cases in which lesion of this center has been associated with localizing symptoms before death. Unfortunately, the capability to describe vividly the symptoms resulting from lesion in this area requires a certain degree of intelligence. The ignorant person, suffering such a lesion, would find himself unable to describe intelligibly his sensations.

In the very few cases whose records I am able to find, the lesion has been associated with a peculiar sensation of unreality. The patient loses the power of appreciating the three dimensions of space; he loses his sense of the solidity of objects, and thus his sense of reality. His attitude toward the third dimension of space is similar to the mental attitude of the normal person to the fourth dimension; it is simply unthinkable. Such a patient, losing his sense of solidity, or reality, becomes unable to realize the existence of objects beyond his immediate environment. So far as his perceptions are concerned, the very fact of his turning his attention away from any object blots it immediately from existence. He becomes unable to perceive objects as having actual existence apart from their immediate and transitory effects upon himself. His mental attitude to any object apart from his immediate environment is similar to the attitude of the normal person to a perfectly remembered dream. There is no ques-

tion of loss of memory; the actual existence of the thing seen in a dream is totally outside of the range of recognized possibility — often is itself utterly unthinkable. Yet one may remember his dream perfectly, and the patient with the lesion in the stereognostic area may remember the things seen and felt, while finding their continued existence apart from their effects upon his senses likewise unthinkable. Astereognosis is, then, comparable to mind blindness, or mind deafness.

The Motor Centers

The motor area includes a number of centers lying along the anterior portion of the postcentral gyrus (ascending frontal convolution), and in the neighboring area of the paracentral lobule. The motor overflow extends toward the front of the area mentioned. In the motor overflow the movement memories are probably located, and the centers concerned in the control of the immediate motor neurons. Probably in the motor overflow are found centers whose activity coördinates the activities of the cells of the motor area, much as the association cells of the cord coördinate the spinal reflexes.

The motor center receives impulses as follows:

I. Impulses from the somesthetic area of the same side, possibly of the opposite side, may affect the activity of the motor cells. This reaction may or may not be conscious.

II. Impulses from the association centers may cause increased or decreased action of the motor cells.

III. Impulses from the speech center affect the activities of the cells motor to the voice muscles.

IV. Impulses from the homologous centers of the opposite hemisphere are concerned in coördinating, in part, the impulses passing to the lateral halves of the body.

The motor center sends impulses as follows:

I. Chiefly, the fibers from the large pyramidal cells of

the motor area descend into the internal capsule, through the crura, the pons and medulla, to become the pyramidal tracts. These fibers ultimately terminate in the center of the gray crescent in the spinal cord and around the cells of the motor nuclei of the cranial nerves. These fibers are carried to the somatic motor, but not to the visceral motor nuclei, under normal conditions.

II. Axons and collaterals from the pyramidal tracts terminate in the optic thalamus, the corpora striata, the substantia nigra, the red nucleus, and probably other of the basal ganglia and related centers, and into the corpus callosum.

III. Axons from cells of the motor area, probably of all layers, carry associational impulses to all other cortical areas.

Lesion of any motor center is associated with paralysis of the upper neuron type of the muscles controlled by that center.

The Anterior Association Area

This area seems to be developed, in right-handed persons, to a greater extent in the left side of the brain than on the right. The anterior association area is continuous, on its posterior aspect, with the somesthetic area. It seems probable, from a study of the phylogenetic development of the frontal lobes, that whatever sensory impulses from the viscera reach the cortical centers at all are carried to the frontal lobes. These areas are separated from the other sense areas of the brain, except as they are associated through the long association tracts. The anterior association area is, then, admirably adapted, structurally, to the coördination of those impulses concerned in the consciousness of personality, the appreciation of external changes in the light of their effects upon self.

This area receives impulses from the following sources:

I. Impulses are carried from the viscera, by way of the indirect sensory paths through the cerebellum and the spino-thalamic tracts, and by way of the vagus, to the thalamus by the fillet, and to the cortex by the thalamic radiations.

II. Impulses are probably carried by way of the spinal sensory tracts, as in the case of the somesthetic areas, directly to the frontal lobes.

III. Impulses from the somesthetic areas of the same side of the cortex are carried to the frontal lobes.

IV. Impulses from the homologous areas of the opposite hemisphere are carried by way of the corpus callosum, probably in part by indirect paths through the commissures.

V. Long association tracts carry impulses from every other part of the cortex to the frontal lobes, especially of the left side.

The anterior association area sends impulses as follows:

I. The anterior association area sends impulses, partly if not chiefly inhibitor, to the various centers at the base of the hemispheres.

II. This area sends impulses to other parts of the hemisphere of the same side, and to the homologous area of the opposite hemisphere.

III. Impulses concerned in the production of volitional movements are carried to the motor center.

IV. Impulses concerned in the performance of the more delicate and highly coördinated acts probably are carried by way of the red nucleus and the brachium conjunctivum to the cerebellum without much, if any, associated stimulation of the motor area.

V. Impulses from the anterior to the middle and the posterior association areas are concerned in the coördination of the ideas of complex relationships involving the place of personality and of many environmental factors.

Injuries or disease of the frontal lobes of the left side,

exclusive of the speech center, are associated with symptoms of uncontrolled emotions and instinctive reactions (see I, above), and with a loss of the patient's place in the midst of things, of his relation to his neighbors and his environment. Rarely the lesions of the frontal lobe alone are associated with stupidity and lack of emotional actions, unless there is also a condition of greatly-increased intracranial pressure.

The Middle Association Area

This is the insula, or island, of the cerebrum (Island of Reil). It lies beneath the cortex, being formed by the infolding of the cortex, which is associated with the formation of the lateral fissure of the cerebrum (fissure of Sylvius).

The cortex of the middle association area is continuous with the speech center, the auditory overlap, the motor center, the somesthetic center, and to a slight extent with the visual overlap.

Its function is not well known. Lesions in this area have been associated with paraphasia, with visual aphasia, and sometimes with no recognizable localizing symptoms before death. The connections of the center are not known, beyond the fact that fibers pass to and from almost or quite all of the other association areas, and probably also other cerebral centers.

The Posterior Association Centers

This area also is most highly developed upon the left side of the brain in the ordinary right-handed person.

This area is intimately associated with the centers of vision and the visual overflow, with the centers for hearing and the auditory overflow, with the centers for somatic sensations, and with the common sensory overflow. For this reason the posterior association area is so placed as to be

adapted to the coördination of these impulses arising from the incoming sensations both general and special, and from the appreciation of the significance of these sensations, as they are received and modified and held through the agency of the neighboring psychical or overflow areas. The posterior association areas receive impulses from the following sources:

I. From the visual, auditory, common sensory and their neighboring areas, both by short and by long association tracts.

II. From the anterior and the middle association areas.

III. From homologous centers on the opposite hemisphere.

IV. From the corpora striata and the optic thalamus, and perhaps from other centers associated with these.

The posterior association area sends impulses to other centers, as follows:

I. Impulses concerned in the performance of movements are sent to the motor area.

II. Impulses concerned in speech coördinations are sent to the speech center and the middle association area.

III. Impulses concerned in the performance of habitual and delicately coördinated acts are probably sent by way of the red nucleus, the brachium conjunctivum and the cerebellum.

IV. Impulses are sent to the middle and anterior association areas which are concerned in the transmission and coördination of the impulses concerned in the more logical mental acts — those underlying the manifestations of the higher intelligence.

Injuries or disease of the posterior association area of the left side are usually accompanied by a loss of the higher mental faculties. Loss of control and the performance of improper emotional and instinctive acts are not characteristic

of lesions of this part of the brain. The patient loses the power to concentrate his thoughts, to work out problems requiring logic or classification or the power of anticipating events; but he is usually docile, self-controlled, and his faults are those rather of stupidity than of passion. It may happen that other symptoms are found in special cases.

The Language Centers

The centers concerned in the expression and recognition of thought are practically limited to mankind. Among animals, the expression of feelings, and, to a certain extent, the conveyance of information of environmental changes, is to be found, though in a very minor degree, when compared with the capacity of mankind. It is not known that thought is to be found among animals as a conscious phenomena, though it is a matter of common knowledge that animals sometimes act as if they had thought.

The language centers probably include in their metabolism and structure some of the most complex and highly specialized activities of which nervous matter is capable. The centers for language include a number of different areas, each of which has its own function. Of these centers, it is probable that each is associated with every other by fiber tracts, and that all of these receive association fibers from the different association areas, from the basal ganglia, from the visual and the auditory overflows, and perhaps from the rhinencephalon, either directly or indirectly. The impulses from each center probably are carried, either directly or indirectly, to the centers of the muscles for the control concerned in the actions necessary to the expression of the thought in some particular manner. The impulses from the writing center, for example, must ultimately reach the motor area for the arm and finger muscles.

The language centers include the following:

The motor speech center occupies the cortex of the left third frontal gyrus. Injury of this center loses the power of speech, though there is no paralysis of the muscles concerned in speech. The patient is unable to form in his imagination the positions of the vocal organs; the muscular memories of speech-making are lost.

The writing center occupies the second frontal gyrus. Lesion of this area causes the loss of the power to write, though no paralysis of the arm or finger muscles is present, nor is there any loss of mentality.

The center for the recognition of the significance of words, the word-naming center, occupies the angular gyrus. The injury of this center causes the loss of the power to write, because that which might be written can not be recognized. Lesion of this center causes loss of the power to read. Words are seen, their forms may be remembered, but the significance of the letters and the words they form are not to be recognized. The condition is that of word blindness.

A center for the recognition of the significance of objects has been described in the right angular gyrus. Injury of this center causes the loss of the memories of the uses of objects. Such a patient should be able to see perfectly, and even to name an object, but he is not able to remember its appearance, nor to determine its use or significance.

A center for gesticulation has been described as occupying the region bordering upon the motor centers for the muscles employed in gesticulations. It seems that such a center must be rather intimately associated with the lower centers for the expression of the instinctive and emotional acts. The evidence in favor of a cortical localization for gesticulation is not conclusive.

The auditory word center occupies the posterior portion of the first temporal gyrus. Lesion of this area causes word deafness. It is usually associated with some motor aphasia.

A center for tone deafness has been described in the second temporal gyrus.

These centers are probably complex in their structure. Probably each center includes a variable number of subordinate centers. The loss of the use of nouns, for example, or of certain languages in polyglots, the phenomena of paraphasia, all indicate that the physiology of the language centers is more complicated than at first appears.

CHAPTER XVIII

THE NERVOUS CONTROL OF SPECIAL FUNCTIONS

The centers located in the different parts of the nervous system have been discussed in their morphological and physiological relations. It seems advisable, for the sake of clearness, to devote a few pages to a discussion of the nervous control of certain functions whose innervation is unusually complex.

The Eye

The pupilo-constrictor and ciliary muscles are innervated by the short ciliary nerves, gray fibers from the ciliary ganglion (lenticular, or ophthalmic ganglion). This ganglion receives its stimulation by way of the visceral motor fibers of the third cranial nerves.

The pupilo-dilator muscles, the non-striated muscles of the levator palpebrarum and the capsule of Tenon, the blood vessels of the eye and the orbit, and the tear glands are innervated from the superior cervical sympathetic ganglion, which is controlled by the upper thoracic centers of the cord.

The eye is subject to the various diseases which are discussed in text-books dealing with the subject. In addition to the etiological factors already well recognized, the place of the bony lesion as an etiological factor must be admitted. Lesions of the upper thoracic vertebræ are efficient factors in the etiology of disturbances of the circulation through the eye

and the orbital tissues, and in interfering with the normal innervation of the pupil and the non-striated fibers of the capsule of Tenon and the levator palpebrarum. These abnormalities of innervation and circulation are important predisposing causes of certain eye diseases, infectious and otherwise.

The Heart

The vagus nerve carries inhibitory impulses to the cardiac ganglia. It carries sensory fibers which may affect the heart's action, and also the tension of the blood vessels over the body, especially of the splanchnic region.

The white rami of the middle upper thoracic region carry impulses, which increase the speed and the force of the heart's beat, to the superior and the middle cervical sympathetic ganglia. The gray fibers from these ganglia join the vagi and are carried with them to the heart, where they are distributed to the muscle fibers. The same pathway which carries the augmentor and accelerator impulses to the heart carries also, probably, impulses which influence the size of the cardiac blood vessels. This matter is not proved. Also, viscero-sensory nerves are carried from the heart, upward with the vagi, and downward with the cardiac accelerators, to the heart center in the middle upper thoracic segments.

Both the vagus center and the middle upper thoracic centers are controlled by a general heart center in the medulla, which may or may not be identical with the vagus center.

The heart may be diseased by the following conditions:

Abnormal pressure in the blood vessels;

Poisonous substances in the blood stream and starvation through poor blood;

Local infection;

Abnormal positions of the first to the fifth thoracic vertebræ and ribs, and muscular tension in the cervical region,

of such a position as to bring the pulsating carotid more closely pressed against the vagus fibers;

Abnormal sensory impulses carried to the centers from other parts of the body, usually viscera innervated by the vagus.

The Nervous Control of the Blood Pressure

The pressure of the blood in the vessels depends chiefly upon two factors: the efficiency of the heart's beat, and the amount of the peripheral resistance. The amount of blood in the vessels becomes a matter of importance in varying the blood pressure only under abnormal conditions. Other factors are to be considered under certain conditions, but are of no interest in this connection.

The efficiency of the heart's beat depends upon two factors: the rate and the force of the contractions. Both of these factors are subject to nervous control, and are discussed in connection with the heart centers.

The peripheral resistance depends chiefly upon the contraction of the muscles of the arterioles. The larger vessels, the veins and the lymphatic vessels, are all supplied with nerves, but the arterioles are best supplied with circular muscles, and it is in the field of the arterioles that the most efficient modifications are made in controlling the pressure of the blood through variations in peripheral resistance.

The vaso-motor centers in the medulla have been discussed elsewhere. It may be repeated that the vaso-motor centers act in accordance with the algebraic sum of the nerve impulses reaching them, and upon the physiological condition of the nerve cells of the center. This center controls the general circulation of the body. It acts in part by sending impulses to the various lower centers in the medulla, pons, midbrain and spinal cord. These centers also have a certain amount of autonomic power. The general blood pressure

may be lowered greatly by loss of tone of the splanchnic centers, for example. The pressure may be greatly increased by an increased activity of the centers controlling any marked area of the circulation, as in the splanchnics or the lungs.

Sensory nerves from all parts of the body act upon the subsidiary centers as well as upon the chief vaso-motor centers. The changes in blood pressure which are initiated by the activity of the lower centers may be sufficient to cause disturbance in the general pressure, and the chief vaso-motor centers in the medulla may act to cause a return to the normal conditions. Constantly, there is in action a balancing of the impulses from the different parts of the nervous system in the vaso-motor centers. Thus the circulation is maintained, with the pressure in the vessels remaining fairly constant, and with those variations in the pressure of the blood and in the caliber of the vessels which are needed by the various organs at different times.

The practical aspect of this question is of great importance. In the first place, the etiological value of the bony lesion in causing disturbances in the pressure of the blood must be recognized. Slight malpositions of vertebræ and ribs, or other forms of peripheral irritation anywhere, may be a source of streams of abnormal sensory impulses which may affect the chief vaso-motor centers, or may affect the subsidiary centers in the cord or medulla. No part of the body can be well nourished if the blood pressure remains too low. Though the patient may be overfat, he is really poorly nourished, since he is unable to use the fuel with which he is provided. The ordinary neurasthenic shows the effect of the low blood pressure in his tendency to fatigue, loss of mental energy and muscular weakness, both real and fancied.

The bony lesion may act also as a source of excessive vaso-motor impulses. In such cases the pressure may be kept at too high a point, and certain organs of the body, notably

the kidneys, liver and heart, are rendered more liable to disease. This condition is not often found existing for any length of time, since the nervous regulation of the heart's action soon brings the pressure to its proper level. The high blood pressure found in arterio-sclerosis becomes a source of danger. Besides the injury to the vessels and the kidneys, liver and heart, the liability to hemorrhage, particularly of the cerebral vessels, must be remembered. In patients suffering from arterio-sclerosis, even of mild type, the existence of a bony lesion may add to the pressure, and thus to the handicap of the heart, in a manner which is destructive.

In the correction of lesions in any part of the body, or in outlining any sort of treatment, or in advising exercises or changes in the habits of living, this question of blood pressure must be considered if the best good is to be accomplished. If the blood pressure is too low, then the movements used in the correction of the bony lesions should be so planned as to send increased sensory impulses into the centers. The movements which are short and quick, with the effect of stimulation to sensory nerve endings in the joint surfaces, are of most value. Such movements add to the stimulation of the centers innervated from the same segments as the articular surfaces affected by the movements; the blood pressure is correspondingly raised, and the general condition of the patient is improved, not only by the actual corrective measures, but also by the corrective methods.

On the other hand, if the blood pressure is too high, especially if the patient suffers from any arterio-sclerosis, the use of the same methods may be responsible for increased injury. The corrective movements indicated in these cases should be given slowly and gently. No increased sensory stimulation should be sent into the centers from the articular surfaces. The lesions may be corrected, but this must be done without increasing the stimulation of the centers. Directions

as to hygienic measures must be given with due regard to the pressure changes liable to occur. With care, the blood pressure may be kept within reasonable limits even while considerable corrective work is being done. Careful watching of the pulse may prevent undue rise of blood pressure in the aged and arterio-sclerotic. The same considerations are important in outlining the treatment and the hygienic advice for patients with cardiac lesions, aneurysms, and all conditions in which a rise of blood pressure is harmful or dangerous.

The Nervous Control of the Blood Quality

The character of the blood depends upon many factors, all of which are more or less under the control of the nervous system.

The blood elements are derived from the food. The digestion and absorption of food is controlled by the nervous system.

The oxygenation of the blood occurs in the lungs. The circulation through the lungs and the respiratory movements are controlled by the nervous system. Under abnormal circumstances the oxygen supply to the tissues may be deficient because of too low hemoglobin percentage in the blood. The increased respiratory movements initiated by the respiratory center increase the rib movements, increase the circulation of the blood through the red bone marrow, and thus tend to bring about the condition needful for the formation of better erythrocytes.

The elimination of the waste products of metabolism occurs in several organs of the body, notably in the liver and the kidneys. The circulation through the kidneys and the liver is controlled through the nervous system, and the rapidity of elimination thus controlled. In the liver and other

organs secretory nerves are recognized. The purification of the blood is thus largely a matter of nerve control.

A more direct control of the hematopoietic organs is recognized. The nerves to the red bone marrow are of two kinds, at least. One class of these nerves includes the vasomotors. These terminate upon the walls of the blood vessels of the red bone marrow. Other nerves terminate by fine fibrillæ which branch freely among the marrow cells. The function of these is not known.

There is not any exact center for the control of the blood character, but the centers controlling the circulation through the bones containing red marrow and the movements of the ribs are efficient in modifying the formation of the blood cells according to the demands of the body and its changing environmental conditions. Lesions affecting these centers may affect the character of the blood.

The Nervous Control of the Muscles

The nervous control of the somatic muscles is rather complex. First must be recognized the volitional control of specific movements. The centers situated in the precentral convolution of the cortex give this volitional control. The large pyramidal cells of this center send axons downward by way of the internal capsule and the pyramidal tracts. In passing through the medulla fibers are given to the cranial somatic motor centers. Part of the pyramidal fibers continue through the medulla and into the spinal cord of the same side. These terminate at different levels of the cord, almost altogether in the cervical and upper thoracic region, by crossing to the opposite side and forming synapses with the cells of the middle part of the gray crescent. These cells in turn send axons to the anterior horn cells, and the axons of the anterior horn cells pass as the motor nerves to the muscles

innervated by these segments — the muscles of the neck, shoulder, arm, hand, and the upper thoracic muscles.

A larger part of the pyramidal fibers decussate in the lower part of the medulla. These pass as the crossed pyramidal tracts through the cord, and terminate in the same manner as described above, except that these fibers carry impulses destined for the muscles of the lower part of the body, pelvis, thighs, legs and feet.

Injury of the centers of the cortex concerned in the control of any muscle group results in the paralysis of that group, so far as volitional movements are concerned. In certain instances the muscles are not paralyzed for instinctive and emotional reactions, nor for the performance of the autonomic acts, as respiration. The reflexes are increased, and the emotional and instinctive acts may become excessively abrupt, by the loss of the inhibitions normally sent from the cortex to the lower centers.

The coördinate action of the muscle groups is secured by the activity of the cerebellum, and perhaps of the olivary body and other centers in the medulla and pons. The cerebellum is able to act in this way through its incoming impulses; those from the cortical centers enable volitional acts to be performed in a coördinate manner; impulses from the vestibular nuclei, the viscera and skin, and from the muscles themselves, enable the movements concerned in the maintenance of the erect position to be coördinated, and the frequent repetition of the impulses passing to and from the cerebrum during repeated actions enables the cerebellar cells to lower their liminal value sufficiently to assume the control of the act repeated, as in the formation of a habit.

The skeletal muscles concerned in the performance of the autonomic acts, as in respiration and the like, are controlled in part by the centers of the medulla and in the spinal cord.

The tone of the skeletal muscles is secured in part through

the stream of efferent impulses carried over the tracts already described. In addition to these impulses, a constant stream of sensory impulses from joint surfaces, viscera, skin and muscles alternately contracting and relaxing during movements of the body, act upon the cells of the anterior horn and stimulate them to constant, slight, normal activity, so that the muscles innervated therefrom are kept in that condition of slight contraction called muscular tone. Structural conditions which lessen this stream of sensory impulses to the centers for the skeletal muscles lessen their tone, cause muscular weakness, and lessen their nutrition.

The control of the muscles concerned in the performance of certain particular acts, such as language, etc., is secured through the activity of certain centers.

The movements concerned in the production of language are coördinated in the third frontal convolution. The movements concerned in writing are coördinated in the second frontal convolution of the cerebral cortex. The movements of the eye muscles, both intrinsic and extrinsic, are coördinated in the anterior quadrigeminates. The movements of the ear muscles, both extrinsic and intrinsic, are coördinated in the posterior quadrigeminates. Injury of these centers is followed by a loss of coördination in the performance of that particular act, but by no paralysis in volitional movements, nor in other coördinations of the same muscles. The woman who lost the power of writing through a lesion of the second frontal convolution could knit with no difficulty. The descending impulses are by way of the pyramidal cells and tracts.

The control of the movements concerned in the instinctive and emotional acts is secured in part by the centers and pathways already described, since these reactions are, in mankind, subject to volitional initiation and control. Centers in the

basal ganglia and the midbrain are concerned in the more direct coördination of these impulses. These centers include the red nucleus and substantia nigra, probably the nuclei of the reticular formation, the sub- and hypothalamic nuclei, and others. The impulses are carried by way of the rubro-spinal tract to the spinal centers, and by the anterior horn cells to the muscles concerned.

The lesions of the cortex permit the uncontrolled activity of the emotional centers. Lesions of the centers themselves are not easily recognized, since loss of the emotional reactions is distinguished with difficulty from the loss of sensory coördinations and of mentality.

The circulation through the muscles is governed by the vaso-motor impulses. These are derived from the lateral horn cells of the cord from about the second thoracic to about the second lumbar segments. The white rami, axons of the lateral horn cells, form synapses with the cells of sympathetic ganglia, and the gray fibers from these cells (fibers of Remak) enter the cerebro-spinal nerves as their "sympathetic roots," and are carried with them to their destination in the walls of the blood vessels. The centers for the control of the circulation of the muscles act according to the algebraic sum of the impulses from the higher centers, from the sensory fibers of the particular segment and its neighbors, and from the muscles themselves.

The nutrition of the muscles seems to be controlled also by the cells of the anterior horns of the cord. Atrophy of these cells in any segments of the cord, however produced, is associated with atrophy of the muscles innervated from those segments. These cells act, in part at least, through receiving and transmitting the impulses received from the cortex, the basal ganglia, the pons, medulla, midbrain and neighboring centers, and from adjacent spinal centers.

The Nervous Control of the Body Weight

The weight of the body depends upon two factors, the income and the outgo. The income includes the foods taken into the body, digested and absorbed, the water taken into the blood stream, and the oxygen breathed in by way of the lungs. The outgo includes the wastes of metabolism eliminated — the carbon dioxid breathed out, the water and other substances excreted by the kidneys, the bile and intestinal secretions which help form the feces, the sweat, and certain other secretions of minor importance in this connection.

The influence of the nervous system upon digestion, absorption and elimination have been discussed in connection with the centers controlling these functions. The food intake is largely a matter of appetite and of convenience, both of which are under the influence of the nervous system to a certain degree. The circulating blood carries the products of the digestion and absorption.

The outgo depends upon a number of factors. The elimination of carbon dioxid is the most variable factor in the elimination. The excretion of carbon dioxid by the lungs depends upon the amount of oxidation occurring in the body. The oxidation processes most subject to variation are those occurring in the skeletal muscles. During muscular exercise there is an increased amount of oxidation, and for this reason exercise is a method of eliminating superfluous fat.

A comparatively great amount of oxidation occurs in the muscles in the maintenance of muscular tone. This is secured through the reflex action of the many sensory impulses, either directly, in the spinal reflexes, or indirectly, through the activities of the higher centers. The tonic condition of the skeletal muscles depends upon the efferent impulses, and these depend in part upon the sensory stimulation, and in part upon the physiological condition of the efferent neurons. Thus it

becomes evident that either a lowered liminal value of the efferent neurons or an increase in their stimuli may be responsible for an increase of muscular tone, and thus an increase in this factor of the outgo. This increase of muscular tone is one factor concerned in the emaciation often found in people of the type commonly called "nervous"—that is to say, people whose nervous systems include neurons which are characterized by an abnormally low liminal value.

Another loss of weight is found in the character of the movements performed by a certain class of people. A lack of coördination sometimes, a lack of proper balance between the nature of movement required and the character of the movement performed is responsible for much waste of muscular effort and for a correspondingly increased oxidation, increased elimination of carbon dioxid and loss of weight.

Certain peripheral irritations may be sources of abnormally increased sensory impulses. Tension upon joint surfaces, the result of slight malpositions of bones, especially vertebræ and ribs, scar tissue in certain parts of the body, eye strain, adenoids, and other irritations of sensory nerves, may initiate such increase of muscular tone as to cause loss of weight. The nervous irritations mentioned are efficient factors in other disturbances also.

The outgo may be decreased abnormally and obesity result. This condition may be due to a number of etiological factors discussed in the text-books devoted to the study of disease. Among these may be mentioned deficient heart action, anemia, constitutional tendency, habits of overeating and underexercising, etc. These factors are partly controlled by the nervous system.

The place of the blood-pressure changes in causing obesity is not well recognized. The oxidation processes depend upon the pressure of blood flowing through the muscles. With too low a blood pressure, or in the presence of

arterio-sclerosis and a deficient blood supply to the capillaries of the muscles, the metabolism of the muscle cells is rendered abnormal. The oxidation processes are more or less incomplete, the amount of energy expended is less than normal, the accumulated fat fails of oxidation, and the patient, even under what seems to him violent exercise, loses nothing in weight. With normal blood, well oxygenated, flowing at a normal pressure through muscles whose tone is kept at their normal level by the impulses from normal nerve centers, it is probable that neither obesity nor emaciation could occur.

TABLE I

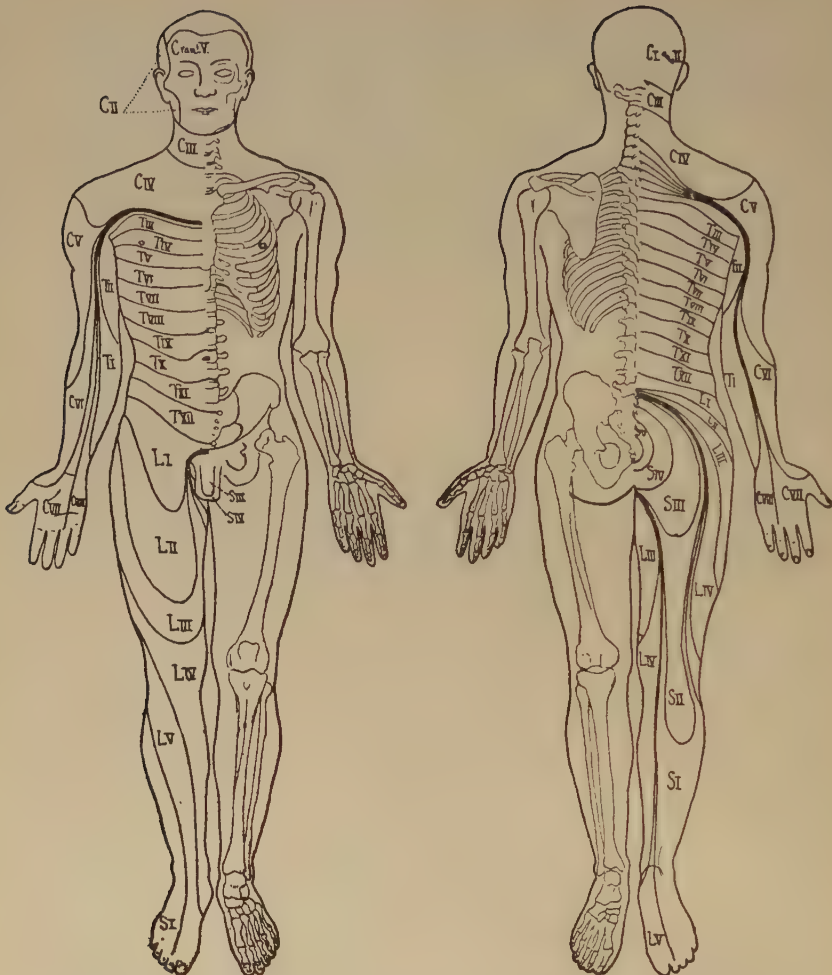
THE OSTEOPATHIC CENTERS

The nerve centers may be affected by sensory impulses from the skin and subcutaneous tissues, as well as from the viscera and joint surfaces. The superficial area in close central connection with any nerve center has been called an "osteopathic center." This term is not unobjectionable, since it is long, awkward, and liable to add to misunderstandings, especially if the qualifying adjective should be inadvertently omitted.

Sensory impulses from the skin, muscles, joint surfaces and viscera innervated from any given spinal segment may affect the motor impulses from that segment. This reaction may be employed with discretion in palliative therapeutics, but the use of such measures, however beneficial temporarily, should not lead to the neglect of those corrective measures which remove the real and ultimate cause of the abnormal condition.

Heat, cold and counter irritants applied to the skin areas innervated from the same segment as the abnormal viscera are more efficient than the same agents applied to other areas. Stimulating and quieting movements may be given over the skin areas innervated from the same segment when direct manipulations would be too painful, and the pain may thus be relieved sufficiently to render the more specific treatment possible. The skin nearest the spinal column, that over the joints, the areas where the skin is folded, as the axilla, and the areas nearest the orifices of the body are most efficient as a source of sensory impulses affecting visceral activities.

The following cut, taken from Osler, gives the segmental innervation of the skin areas. The visceral innervation from the corresponding segments is modified from Sherrington. Stimulating movements affecting the joint surfaces innervated from any segment increase the efferent impulses from that segment, in general.



The left side of the body shows the segmental skin fields, the right side shows the skeleton. The heavy lines represent the axial lines of the limbs. (From Osler.)

Visceral Innervation of the Corresponding Segments.

Modified from Sherrington.

D I. Pupilo-dilator; mucous membranes and glands of head.
D II. Pupilo-dilator; mucous membranes and glands of head and neck; lungs; cardio-accelerator.
D III. Pupilo-dilator; mucous membranes and glands of head, neck and upper thorax; lungs; cardio-accelerator.
D IV. Pupilo-dilator; mucous membranes of head, neck and thorax; cardio-accelerator; lungs.
D V. Mucous membranes and glands of neck and thorax; cardio-accelerator; spleen and stomach.
D VI. Lungs, heart, upper abdominal organs.
D VII. Lungs, heart, upper abdominal organs.
D VIII. Upper abdominal organs.
D IX. Abdominal organs, kidney.
D X. Abdominal organs, kidney, ureter, ovary, testis.
D XI. Abdominal and urinary organs, internal generative organs.
D XII. Abdominal and urinary organs, internal generative organs.
L I. Lower intestines and internal sphincter, bladder, prostate and uterus, above os.
L II. Lower intestines and internal sphincter, bladder, prostate and uterus, above os.
L III, L IV, and L V, relations uncertain.
S I. Bladder.
S II and S III. Bladder, anal tissues, external generative organs.

TABLE II

TRACTS

The following table gives the origin and destination of the more important fiber tracts in the nervous system. It is understood that the fibers of any tract are the axons of nerve cells situated in the place of origin of the tract, and that the fibers terminate by forming synapses with the cells in the place of their destination. The impulses are carried in the direction of the growth of the axons, from the origin of the tracts to their destination. Only the chief fibers of any tract are given here, though many tracts carry a few fibers which have different origin or termination, or both. These are described in the text, or may be found discussed at length in books devoted to the minute structure of the nervous system:

Acustico-cerebellar Tract — From the nucleus fastigii and the nucleus globosus to Dieter's nucleus of the opposite side.

Ansa Lenticularis — From the cerebral cortex to the corpus striatum; from the striatum to the cortex.

Ansa Peduncularis — From the cerebral cortex to the optic thalamus; from the thalamus to the cortex.

Anterior Ascending Cerebello-spinal — See Cerebello-spinal.

Anterior Cerebro-spinal — See Cerebro-spinal.

Anterior Commissure — From the olfactory area of each side to the olfactory area, the nucleus amygdala and the uncus of the opposite side; from the tentorial area of each side to the tentorial area of the opposite side.

Anterior Longitudinal Bundle — See Longitudinal Bundle.

Arcuate Fibers, External — From the nucleus cuneatus and the nucleus gracilis to the olivary body and the cerebellum of the opposite side.

Arcuate Fibers, Internal — From the nucleus cuneatus and the nucleus gracilis to the lateral nucleus of the thalamus of the opposite side, by way of the medial fillet.

Brachium Conjunctivum (superior cerebellar peduncle) — Chiefly from the dentate nucleus to the red nucleus of the opposite side; partly from the red nucleus to the contralateral dentatus.

Brachium, Inferior — From the inferior colliculus to the medial geniculate body; from the acustic nuclei to the medial geniculate body.

Brachium Pontis — Chiefly, from the nucleus pontis to the contralateral hemispheres; partly, from the cerebellar hemispheres to the nucleus pontis and the nuclei of the reticular formation.

Brachium, Superior — Chiefly, fibers of the optic radiation; partly, fibers of the optic tract; it connects the superior colliculus with the lateral geniculate body.

Burdach — See Cuneatus.

Capsule, External — Subcortical fibers external to the lenticular nucleus; from cortical areas to adjacent areas.

Capsule, Internal — From the thalamus and striatum to the cortex; from the cortex to the thalamus, striatum and adjacent centers.

Cerebellar Peduncles — See Restiform Body, Brachium Pontis, and Brachium Conjunctivum.

Cerebello-olivary Tract — From the cerebellar cortex, perhaps also the cerebellar ganglia, to the olivary bodies of both sides.

Cerebello-spinal Tract, Anterior Ascending (tract of Gowers) — From the dorsal nucleus and posterior horn of the cord to the cerebellum by way of the brachium conjunctivum.

Cerebello-spinal Tract, Anterior Descending — From the cerebellar cortex, perhaps cerebellar ganglia, to the spinal gray matter of all levels.

Cerebello-spinal Tract, Posterior Ascending (direct cerebellar tract, tract of Flechzig) — From the dorsal nucleus and posterior horn of the cord to the superior vermis by way of the restiform body.

Cerebro-spinal Tract, Anterior (direct pyramidal tract) — From the pyramidal cells of the middle one-half of the anterior central gyrus to the central part of the opposite crescent of the cord, chiefly above the midthoracic region.

Cerebro-spinal Tract, Lateral (crossed pyramidal tract) — From the upper one-third of the anterior central gyrus to the opposite crescent of the cord, chiefly below the midthoracic region.

Cerebro-pontal — From the cerebral cortex to the nucleus pontis.

Ciaglinski's Tract — From the posterior horns and sensory ganglia to upper sensory centers (doubtful).

Cingulum — A complex bundle associating the anterior perforated space, gyrus cinguli, hippocampus, uncus and temporal pole.

Comma Tract — From the sensory ganglia, descending branches from the posterior root fibers of the cord, to the spinal gray matter of levels one or two segments below.

Corpus Callosum — From the cerebral cortex to the contralateral cerebral cortex.

Cortico-striate — From the cerebral cortex to the corpus striatum of the same side.

Crossed Pyramidal Tract — See Cerebro-spinal, Lateral.

Cuneatus, Fasciculus — From the spinal sensory ganglia to the nucleus cuneatus of the same side.

Direct Cerebellar — See Cerebello-spinal.

Direct Pyramidal — See Cerebro-spinal.

External Arcuate — See Arcuate, External.

Fibers of Remak — Sympathetic fibers, non-medullated, carried with the cerebro-spinal nerves from the sympathetic ganglia to the walls of the blood vessels, glands, etc.

Fillet, Lateral (lateral lemniscus) — From the auditory nuclei to the inferior colliculus and the medial geniculate body.

Fillet, Medial (medial lemniscus) — From the nucleus cuneatus and the nucleus gracilis to the lateral nucleus of the optic thalamus. It recieves, also, fibers from the sensory nuclei of the medulla and pons, except the auditory, and gives fibers to the cranial motor nuclei and to the colliculi and certain other association centers during its course.

Flechzig's Tract — See Cerebello-spinal.

Fornix — From the olfactory bulb and area to the hippocampus and uncus; from the uncus, hippocampus and fascia dentata to the same structures of the opposite side, and to the nucleus habenulæ and the corpora mammillaria of both sides.

Fronto-pontal — From the frontal lobe to the nucleus pontis.

Goll — See Gracilis.

Gower's Tract — See Cerebello-spinal, Anterior Ascending.

Gracilis, Fasciculus (tract of Goll) — From the sensory ganglia to the nucleus gracilis of the same side.

Ground Bundle — See Proprius.

Gudden's Commissure (inferior commissure) — From the medial geniculate body of each side to that of the opposite side, by way of the optic tracts and chiasma.

Helwig's Tract — See Olivo-spinal.

Inferior Commissure — See Gudden's Commissure.

Intermediate Tract — From the striatum to the substantia nigra, nucleus pontis and cranial motor nuclei.

Internal Capsule — See Capsule, Internal.

Lateral Cerebro-spinal — See Cerebro-spinal, Lateral.

Lemniscus — See Fillet.

Lateralis Proprius — See Proprius Lateralis.

Lissauer's Tract — See Marginalis.

Longitudinal Bundle, Anterior (tecto-spinal tract) — From the superior colliculus to the motor nuclei of the eye muscles and related centers; to the cilio-spinal center and to the spinal gray matter of all levels.

Longitudinal Bundle, Medial (posterior longitudinal bundle) — From the gray matter of the cord to the motor nuclei of the cranial nerves;

from the nuclei of the reticular formation to the spinal gray matter of all levels; from each nucleus of the motor oculi nerves to other motor oculi nuclei, and to nuclei of related function.

Mammillaris Princeps — From the corpora mammillaria to (*a*) the anterior nucleus of the thalamus, (*b*) the central gray matter around the aqueduct.

Marginalis, Fasciculus (Lissauer's tract) — From the sensory ganglia (short ascending branches of the posterior root fibers) to the gelatinous substance of the posterior horns of levels one or two segments above.

Medial Lemniscus — See Fillet.

Medial Longitudinal Bundle — See Longitudinal Bundle, Medial.

Meynert's Fasciculus — See Retroflexus.

Non-cruciatus, Fasciculus — The non-decussating fibers of the optic tracts.

Occipito-frontalis — From the occipital cortex to the cortex of the frontal lobe.

Olfactory Tract — From the olfactory lobe to the olfactory area and into the tracts of the rhinencephalon.

Olivary Tract (or fasciculus) — From the lentiform nucleus to the olivary body.

Olivo-spinal — From the olivary body to the spinal gray matter of all levels.

Optic Tract — From the nasal half of the retina to the lateral geniculate body, optic thalamus and superior colliculus of the opposite side; from the temporal half of the retina to the same bodies of the opposite side; the fibers are called optic nerves before the partial decussation in the chiasma.

Pedunculo-mammillaris — From the corpora mammillaria to the gray matter around the aqueduct.

Ponto-spinal Tract — From the nuclei of the reticular formation to the spinal gray matter of both sides and all levels.

Posterior Cerebello-spinal — See Cerebello-spinal.

Posterior Commissure — From the roof of each side of the midbrain to the roof of the opposite side of the midbrain; it contains certain other fibers.

Posterior Longitudinal Bundle — See Longitudinal Bundle, Medial.

Princeps Mammillaris — See Mammillaris Princeps.

Proprius, Fasciculus, Anterior — From the anterior spinal gray matter of any level to the opposite spinal gray matter of the opposite side and the same side, of the same and adjacent levels.

Proprius, Fasciculus, Lateral — From the spinal gray matter of any level to the spinal gray matter of other levels, usually adjacent.

Proprius, Fasciculus, Posterior — From the posterior spinal gray matter of any level to the spinal gray matter of other levels, not usually more than one or two segments distant.

Pyramidal Tracts — See Cerebro-spinal.

Rami Communicantes, Gray — From the sympathetic ganglia to the cerebro-spinal nerves, to be distributed with them to vessels, glands, etc.

Rami Communicantes, White — From the lateral gray matter of the spinal cord, chiefly of the thoracic region, to the sympathetic ganglia.

Respiratory Bundle — See Solitarius.

Restiform Body (inferior cerebellar peduncle) — From the nucleus cuneatus, nucleus gracilis, dorsal nucleus of the cord, and related nuclei, to the cerebellar cortex, chiefly of the superior vermis.

Retroflexus, Fasciculus (Meynert's bundle) — From the nucleus habenulæ to the ganglion interpedunculare and neighboring gray matter.

Rubro-spinal Tract — From the red nucleus and related centers to the spinal gray matter of all levels, to the motor nuclei of the cranial nerves, and to the viscero-motor centers in the medulla.

Septo-marginal Tract — From the sensory spinal ganglia to the gray matter of the cord of lower levels; continuous with the comma tract.

Solitarius, Fasciculus (respiratory bundle) — From the nervus intermedius to the nucleus solitarius.

Spino-thalamic Tract — From the dorsal nucleus and posterior horns of the cord to the lateral nucleus of the thalamus.

Spino-vestibular Tract (vestibulo-spinal) — From the vestibular nuclei to the spinal gray matter of all levels.

Striato-thalamic Tract — From the striatum to the thalamus and hypothalamus and related centers of both sides.

Superior Commissure — The decussating fibers of the striato-thalamic tract.

Tecto-spinal Tract — See Longitudinal Bundle, Anterior.

Temporo-pontal — From the temporal lobes to the nucleus pontis.

Thalamo-mammillaris (bundle of Vicq d'Azyr) — From the corpora mammillaria to the anterior nucleus of the fornix.

Thalamo-striate — From the lateral nuclei of the thalamus and lower centers of the sensory path to the corpora striata.

Uncinate Fasciculus — From the uncus and adjacent temporal cortex to the orbital and adjacent gyri of the frontal lobe.

Vestibulo-spinal Tract — From the vestibular nuclei to the spinal gray matter of all levels.

Vicq d'Azyr — See Thalamo-mammillaris.

GLOSSARY

Afferent—Carrying impulses toward the central nervous system, or toward the cortex.

Agraphia—Loss of the power of writing.

Ala cinerae—An area of gray matter in the floor of the fourth ventricle. It marks the common nucleus of the ninth and tenth cranial nerves.

Alexia—Loss of the power to read.

Amygdaloid (almond shaped)—A. tubercle, a swelling in the floor of the posterior horn of the lateral ventricle, produced by a thickening of cortex. It is a part of the rhinencephalon.

Angular gyrus—The gyrus which closes the posterior end of the superior temporal sulcus. It lies in the area of visual overflow, and is occupied by visual associations, conscious or unconscious.

Ansa—A loop. A. lenticularis, a bundle of fibers connecting the lenticular nucleus with the cortex, the upper lamina of the internal capsule. A. peduncularis, a bundle of fibers connecting the thalamus with the cortex, the lower lamina of the internal capsule.

Aphasia—Loss of the power of speech.

Aqueduct of the cerebrum—A channel which connects the third ventricle with the fourth ventricle. It is about an inch long.

Arbor vitae—The treelike appearance of the cerebellum on section. It is caused by the infolding of the cortical gray matter upon the white core.

Archipallium—The primitive brain; the part of the hemispheres first developed; the rhinencephalon.

Arcuate fibers—Fibers following the course of part of a circle; internal arcuate fibers, those from the nucleus gracilis and nucleus cuneatus passing into the fillet; external arcuate fibers, those which surround the olivary nucleus externally. They include fibers from several sources.

Arterial circle (circle of Willis)—An arterial anastomosis composed of the posterior communicating arteries, the anterior cerebral arteries, and the anterior communicating arteries, all derived from the basilar and the internal carotid arteries.

Association—A term applied to those neurons, tracts or centers which are concerned in relating the parts of the nervous system at different levels.

GLOSSARY

Axon—The emissive prolongation of the neuron. It is characterized by the absence of tigroid substance; its origin from an implantation cone; its constant diameter, the right or recurrent angle of its branchings, and sometimes its great length.

Axon hillock—The implantation cone, an area of the protoplasm of a neuron from which the axon arises. It contains no tigroid substance.

Axis cylinder—The axon; the nervous part of the peripheral nerve.

Basis pedunculi—The crusta of the cerebral peduncle, the part of the peduncle ventral to the substantia nigra.

Brachium—An arm. B. conjunctivum, the bundle of fibers which connects the cerebellum and midbrain, the superior cerebellar peduncle. B. pontis, the bundle of fibers which connects the cerebellum and pons, the middle cerebellar peduncle. Superior B., the bundle of fibers which connects the superior quadrigeminate with the lateral geniculate body. Inferior B., the bundle of fibers which connects the inferior quadrigeminate body to the medial geniculate body.

Calamus scriptorius (the writing pen)—The gray matter at the inferior angle of the floor of the fourth ventricle.

Calcar avis—A swelling along the inner wall of the posterior horn of the lateral ventricle produced by a thickening of the infolded calcarine fissure.

Calcarine fissure—A fissure in the inferior and median aspect of the occipital lobes. It is partly occupied by the visual area.

Capsule—The sheets of white fibers beneath the cerebral cortex. Internal C., the sheet of fibers between the thalamus and the striate body. External C., the sheet of fibers between the striate body and the cortex.

Cauda equina—The inferior continuation of the spinal cord and membranes. It includes the filum terminale with the roots of the lumbar and sacral nerves.

Chiasma opticum (optic chiasm)—The partial decussation of the optic tracts. The fibers of the chiasm include (*a*) fibers from the temporal halves of both retinæ, which do not decussate, (*b*) fibers from the nasal halves of both retinæ, which decussate, (*c*) fibers from the medial geniculate body of each side as they pass to the same contralateral body. The last fiber group is not concerned in the visual path.

Chromophilic—Having an affinity for stains. C. cells, those capable of being deeply stained. C. masses, the tigroid masses, or Nissl's substance, masses of deutoplasmic particles in the protoplasm of the normal resting neuron which take certain stains with especial avidity. They are supposed to represent the stored potential energy of the neuron.

Ciaglinski's tract—A long sensory tract lying in the posterior commissure of the spinal cord. Its existence and relations are not certainly known.

Cilio-spinal—Pertaining to the eye centers and the spinal cord. C. center, a group of nerve cells in the upper thoracic cord which is concerned in the control of the orbital structures.

Caudate nucleus—That part of the striate body which lies under the floor of the lateral ventricle, and which curves from an anterior headlike swelling to a posterior narrow taillike termination continuous with the amygdaloid nucleus.

Cellulifugal—Carrying impulses from the cell body.

Cellulipetal—Carrying impulses toward the cell body.

Center—A group of nerve cells in which the nerve impulses controlling any function are coördinated. C. of origin, a group of nerve cells whose axons make up a motor nerve. C. of termination, a group of nerve cells among which the axons of a sensory nerve terminate.

Cephalization—The headward tendency of parts in phylogenetic development; the tendency of the centers to move forward, and of organs to become innervated from centers more anteriorly placed.

Cerebellum (little brain)—The mass of nerve matter developed from the metencephalon; the chief organ for the coördination of muscular movements.

Cerebrum—The brain, the nervous matter included in the skull anterior to the tentorium cerebelli; commonly, the two hemispheres.

Cingulum (girdle)—A bundle of fibers in the gyrus fornicatus which encircles the corpus callosum. It is concerned in associating the olfactory areas.

Circle of Willis—See Arterial circle.

Clarke, column of—See Nucleus dorsalis.

Collaterals—Branches from axons. These are usually of about the same caliber as the axon, and are given off at a right or recurrent angle.

Claustrum—A layer of gray matter lying beneath the insula and lateral to the external capsule. It resembles the deeper layers of the cortex in structure. Its specific function is not known.

Colliculus (a yoke)—Anterior C., the anterior pair of quadrigeminate bodies concerned in the control of the movements of the intrinsic and extrinsic eye muscles. Posterior C., the posterior pair of quadrigeminate bodies concerned in the control of the intrinsic and extrinsic ear muscles and in the transmission of auditory impulses cephalad.

Column, of the spinal cord—Cells arranged vertically through the gray matter; originally applied to the curving surfaces of the external aspect of the cord.

Comma tract—A bundle of short descending fibers of the spinal cord, the descending branches of the incoming fibers of the posterior roots of the cord, passing to levels one or two segments lower.

Cortex (bark)—The outermost layer of any structure; applied to the layer of gray matter upon the outer aspect of the cerebrum and the cerebellum.

Cuneus—A wedge-shaped gyrus upon the inner aspect of the occipital lobe. It is occupied in part by the visual overflow.

Cuneate tubercle—The swelling on the floor of the fourth ventricle, produced by the nucleus cuneatus.

Cuneatus—See Nucleus cuneatus.

Corpora albicantia—See C. mammillaria.

Corpora mammillaria—Two bodies situated beneath the crura cerebri. These receive the descending fornix fibers, and send fibers to different parts of the thalamus, midbrain and pons. The bodies are part of the olfacto-somatic reflex arcs.

Corpora geniculata—These bodies include two pairs. C. G. medialis, or the median geniculate body, lies upon the postero-median aspect of the thalamus. It is concerned in carrying the impulses for hearing toward the acustic area of the cortex. C. G. laterale, or the lateral geniculate body, lies on the posterior aspect of the thalamus, lateral to the body just mentioned.. It is concerned in transmitting the impulses for seeing to the visual area of the cortex.

Corpora quadrigemina—See Colliculus.

Corpora striata—This body lies within the cerebral hemisphere. It includes the caudate nucleus and the lenticular nucleus, q. v.

Chromatolysis—The destruction of the tigroid masses. C. occurs during excessive overstimulation of the neurons, or in the presence of poisons, increased heat, etc.

Corpus callosum—A thick sheet of fibers which connects the two hemispheres.

Corpus dentatum—A mass of gray matter in each cerebellar hemisphere. Its folded appearance gives it the name.

Corpus pineale (the pineal body)—A structure, reminiscent of the medial eye, lying in the midline just anteriorly to the superior colliculus.

Corpus restiforme (the restifrom body)—A large bundle of fibers which passes into the cerebellum; the inferior cerebellar peduncle.

Corpus trapezoideum—A mass of fibers from the auditory nuclei which form a trapezoidal outline in section through the upper medulla. It is part of the auditory conduction path.

Degeneration—Retrogressive metabolic changes, associated with abnormal conditions of structure or environment. D., Wallerian, the degeneration which occurs in the part of a nerve fiber dissociated from the cell body. D., Nissl's, the atrophy which occurs in a neuron which fails to receive its normal stimulation, or whose cellulifugal impulses are impeded for a long time.

Decussation—A crossing of fibers. Qualifying terms are self-explanatory, as decussation of the fillet, of the pyramids, etc.

Dieter's cell—See Golgi.

Dendrites—Protoplasmic prolongations of the nerve cell. Dendrites are characterized by their treelike branching, their decreasing caliber, the tigroid masses with their protoplasm, usually their short length, and their cellulipetal function.

Dentate nucleus—See Corpus dentatum.

Diencephalon—The midbrain.

Dieter's nucleus—Nucleus of termination of the vestibular nerve.

Direct cerebellar tract (cerebello-spinal)—See Table II.

Direct pyramidal tract—See cerebro-spinal, Table II.

Dorsal nucleus (Clarke's column)—A mass of cells at the base of the posterior horn of the cord, chiefly in the thoracic region.

Efferent—Carrying impulses away from the central nervous system.

Epiphysis—See Corpus pineale.

Epistriatum—An area of gray matter above the corpus striatum in lower vertebrates. It probably is the anlage of the cortical parts of the rhinencephalon.

Eminentia cinerea—A swelling on the floor of the fourth ventricle in the region of the ala cineræ, due to the presence of the vagus nucleus.

Encephalon (the brain)—The term is applied to the hemispheres particularly.

Ependyma—The layer of cells lining the cerebral and spinal ventricles. It is derived from the infolded epiblastic cells, and is ciliated in certain parts of the neural cavities.

External arcuate fibers—See Arcuate.

External capsule—See Capsule.

Falx cerebri—A double fold of the inner layer of the dura mater which dips between the cerebral hemispheres. It includes within its layers in the lower part the inferior sagittal sinus, and in the triangular space between its two layers and the outer layer of the dura, lining the skull, the superior sagittal sinus.

Falx cerebelli—A double fold of the inner layer of the dura mater which dips between the hemispheres of the cerebellum.

Fascia dentata—An infolded part of the cerebral cortex, anterior to the hippocampus. It is absent in anosmatics, is poorly developed in hyposmatics, and is concerned in the olfactory sense.

Fasciculus (a bundle of fagots)—A bundle of nerve fibers having a common course, and usually a common origin or destination, or both. See Table II.

Fillet (ribbon or band)—A bandlike bundle of fibers. Lateral F., or lem-

niscus, a tract from the auditory centers, terminating in the posterior colliculus, and in the medial geniculate body. It carries auditory impulses. Medial F., a tract composed of axons of the nucleus gracilis, nucleus cuneatus, and the nuclei of common sensation and taste in the medulla; it terminates in the lateral nucleus of the thalamus, after giving off certain branches during its course.

Filum terminale—A bundle composed mostly of connective tissue, with a small amount of nervous matter, representing the lower prolongation of the spinal cord.

Fissure—A furrow in the brain, either produced by clefts between the embryonic vesicles, or of such depth and structure as to involve the entire wall of the hemispheres, or to produce eminences upon the walls of the lateral ventricles.

Fornix—A bundle of fibers which associates the anterior and the posterior parts of the rhinencephalon. It includes fibers from several sources and of several destinations, all of them concerned in the transmission of impulses ultimately olfactory.

Funiculus (a little rope)—One of the rounded aspects of the spinal cord, resembling a column. Three funiculi are found on each side of the cord. The term is applied also to bundles of fibers, as a synonym of fasciculus.

Ganglion—A collection of nerve cells associated for the performance of some particular function, but not necessarily capable of coördinating nerve impulses. The term is an anatomical one, and no physiological significance is implied in its use.

Gasserian ganglia—See Semilunar ganglion.

Gelatinosa—A substance found around the neural canal and over the head of the posterior horn in the cord, also in other situations in smaller amounts. It is composed of neuroglia, with small nerve cells interspersed within it.

Genetic—Giving origin to. G. nucleus, a group of nerve cells whose axons make up a motor nerve.

Geniculate—See Corpora geniculata.

Globus pallidus—Two ganglionic masses of gray matter lying beneath the cortex of the hemispheres. These are the inner part of the lenticular nucleus, and are so called because they are rather poorly supplied with blood, and also because the cells of which they are composed contain no pigment. Their function is not well known.

Golgi cells—The term is often applied to the cells which Golgi called Type II. These cells have a single short axon, which exhausts itself by frequent branching in the immediate neighborhood of the cell body. Golgi's Type I cell gives off a long axon, which passes out of the gray matter, or at any rate reaches to a great distance from the cell body. Later authors call the Type I of Golgi the "Dieter's" cell.

Goll (tract or column of)—See Fasciculus gracilis, Table II.

Gower's tract—See Cerebello-spinal, Table II.

Gyrus—An infolding of the cerebral cortex not produced by the embryonic vesicles, and not so deep as to produce indentations upon the walls of the cerebral ventricles.

Helwig's tract—See Olivo-spinal, Table II.

Hippocampus—A swelling upon the floor of the posterior horn of the lateral ventricle, produced by the hippocampal fissure. The infolding of the cortex of the hippocampal fissure produces the structure known as the "horn of Ammon."

Hypophysis—The pituitary body, a structure arising in part from the pharyngeal membrane and in part from the floor of the third ventricle. It includes nervous matter of unknown function and also glandular matter, which elaborates an internal secretion, which is of great importance, but of whose nature very little is known.

Hypothalamus—The masses of gray matter lying beneath the thalamus, including the zona incerta, the nucleus hypothalamicus (Luy's body), and the stratum dorsale. The hypothalamic region seems to be concerned in the instinctive and emotional reactions.

Infundibulum—A depression in the floor of the third ventricle which leads into the hypophysis. It does not remain open after a very early period of embryonic development.

Insula (the island of Reill)—A part of the cerebral cortex which became infolded during embryonic development as a result of the deepening of the lateral cerebral fissure (of Sylvius). It can be seen only by separating the lips of the fissure, or by cutting away the operculum which overhangs it. The insula is an association area of whose function little is known.

Innervation—The act or process of transmitting nerve impulses to, as to a muscle or gland. The term is applied to structures external to the nervous system, and is used in relation to the source of the nerve impulses to any structure.

Intumescentia—A swelling. I. cervicalis, the cervical enlargement of the spinal cord. I. lumborum, the lumbar enlargement of the cord.

Internal capsule—See Capsule, internal

Island of Reill—See Insula.

Interbrain—The thalamencephalon, the region of the thalamus, hypothalamus, and part of the walls of the third ventricle. It is developed from the posterior portion of the first primitive vesicle.

Iter a tertio ad quartum ventriculum—See Aqueduct of the cerebrum.

Karyochrome—A nerve cell whose nucleus occupies almost the entire cell.

Lemniscus—See Fillet.

Limbic lobe—A part of the cortex which lies on its median aspect above the corpus callosum, and on the inner inferior aspect of the hemisphere. It is part of the rhinencephalon and is rudimentary in the human brain.

Limen—A threshold. L. insulæ, the line at which the insula is continuous with the anterior perforated space.

Liminal value—The amount of stimulation necessary to cause the initiation of a nerve impulse by a neuron; the efficient stimulus of any cell or cell structure.

Localization—The recognition of the function of any particular area, particularly applied to the cortical areas.

Locus ceruleus—An area in the floor of the fourth ventricle, which is of a grayish blue color, because of the pigment of its cells.

Lyra, or lyre—Commissural fibers between the diverging crura of the splenium, supposed to resemble the strings of that instrument.

Mammillary bodies—See Corpora mammillaria.

Medullation—The process of becoming medullated, or covered with the medullary sheath, the white substance of Schwann.

Medullary sheath—The myelin sheath, the white substance, fatty and homogeneous, which is formed around the fibers of the cerebro-spinal nerves (except the olfactory) in the order of their assumption of function.

Meninges—The membranes which surround the brain and cord. The outer is the dura mater, the middle layer is the arachnoid, and the innermost, lying next the brain or cord, is the pia mater.

Metathalamus (upon the thalamus)—The geniculate bodies, which lie upon the posterior aspect of the thalamus.

Moss fibers—The incoming fibers of the cerebellum, which terminate in mosslike branchings in relation to similar terminations of the dendrites of the small multipolar cells of the cerebellar cortex.

Moss cells (the term is rather indiscriminately used by different authors)—Neuroglia cells whose branches are fine and mossy in appearance; nerve cells whose dendrites are of mossy appearance.

Myelin—The white substance of Schwann, the medullary sheath.

Myelinization—The process of becoming invested with myelin; medullation.

Neopallium (new brain mantle)—That part of the cerebral cortex not included in the archipallium or rhinencephalon; the part concerned in cerebral functions exclusive of smell.

Neural—Pertaining to the nervous system. N. canal, the canal through the spinal cord; the sixth ventricle.

Neuraxone—The axon.

Neuroblast—The cells of early embryonic life which become developed into neurons.

Neuroglia (nerve glue)—Cells descended from the same epiblastic cells which give origin to the neurons, but which have been developed with the power of reproduction, but no marked irritability. Neuroglia is functionally the connective tissue of the central nervous system; it supports and confines the neurons, the fibers, and the various vessels which nourish these.

Neurilemma—The thin connective sheath which surrounds the nerve fibers outside of the central nervous system. It surrounds both sympathetic and cerebro-spinal nerve fibers, and at the roots of the nerves is continuous with the pia mater.

Neuron—A nerve cell with all of its branches, including the nerve endings in neurons of the first order.

Nissl—See Degeneration and Tigroid.

Nucleus—The nutritive center of a cell; (2) a collection of nerve cells whose fibers form a tract or nerve; hence, the nutritive center of a tract or nerve.

Nucleolus—A small body of deeply-staining substances found within the nucleus of nerve cells and of other cells.

Nucleus ruber (red nucleus)—A mass of cells lying beneath the aqueduct and the third ventricle. It is associated with the cortex and the basal ganglia, and with the lower centers. It appears to be concerned in the coördination of the instinctive and emotional reactions.

Node (a knot)—A joint or lump. N. of Ranvier, those points in the course of a nerve fiber at which the myelin sheath is interrupted and the neurilemma is in contact with the nerve fiber.

Operculum—That part of the cortex, chiefly of the parietal lobe, which overhangs the insula. The operculum properly includes also a part of the temporal and the frontal lobes.

Overflow—Cortical area adjacent to areas of specific function; concerned in associational process which may or may not be conscious.

Perikaryon (around the kernel)—The part of the neuron which immediately surrounds the nucleus; the cell body, exclusive of the long prolongations.

Prevertebral—Anterior to the vertebræ. P. ganglia, those sympathetic ganglia which are located anterior to the lateral chain of ganglia, as the semilunar ganglion, the ganglia of the cardiac and pulmonary plexuses, etc.

Prosencephalon—That part of the nervous system developed from the first cerebral vesicle, the hemispheres with the corpora striata and the optic thalamus and the adjacent structures.

Psychic—Pertaining to consciousness.

Pulvinar (a pillow)—A swelling upon the median aspect of the thalamus. It receives a large proportion of the optic tract fibers, and is a way station in the path of the impulses concerned in vision.

Putamen—The outer mass of gray matter of the lenticular nucleus.

Quadrigeminate—See Colliculus.

Radix, root—The groups of fibers leaving the central nervous system, as the anterior or posterior roots of the cord, the roots of the cranial nerves, etc.

Red nucleus—See Nucleus ruber.

Reflex ("turned back")—The action which results from the stimulation of sensory neurons, affecting efferent neurons, without the intermediation of consciousness. It is not essential that the action be unconscious, but only that consciousness, or volition, shall not affect the action.

Restiform body ("rope-shaped")—The inferior cerebellar peduncle. See Table II.

Rhinencephalon—The part of the brain concerned in the sense of smell. It is the part of the brain first to become functional in phylogenetic development.

Rhombencephalon—The part of the brain developed from the posterior vesicle. It includes the metencephalon and the myeloncephalon, the cerebellum, pons and medulla.

Rubro-spinal tract—See Table II.

Schwann—Sheath of, the neurilemma. Substance of, the myelin sheath which surrounds the nerve fibers of the central nervous system.

Semilunar ganglion—The Gasserian ganglion, the sensory ganglion of the trigeminal or fifth cranial nerve.

Septum pellucidum—The membrane which separates the lateral ventricles.

Somesthetic—Pertaining to the body sensations; that part of the cerebral cortex in which the sensations of the body are registered; the Rolandic area, the area lying about the central fissure.

Stereognosis—The sense of appreciating the elements of the external world as having extension in three directions; the sense of solidity; the power of appreciating the solidity of things seen.

Strand cells—Those cells in the cord whose axons enter into the spinal tracts. Also called Dieter's cells and Golgi Type I cells.

Subiculum—The lower wall of the hippocampus.

Sulcus—A groove upon the surface of the cortex, not deep enough to indent the ventricular wall, nor developed from the deep furrows between the embryonic vesicles.

Sensorium—The cortical areas concerned in consciousness of sensations.

Somatic—Pertaining to the body wall.

Somato-motor—Controlling the skeletal muscles.

Somato-visceral—A term applied to those reflex actions which are initiated by somatic sensory impulses, affecting the visceral structures.

Stimulus—The agent which acts upon nerve or other tissues in such a manner as to change their activity.

Stimulation—The process of changing the activity of nerve or other tissues.

Tegmentum—The part of the cerebral peduncles which lies between the aqueduct and the substantia nigra.

Telencephalon—The endbrain, that part of the nervous system developed from the anterior portion of the anterior vesicle; it includes the hemispheres, corpus callosum, fornix, etc., to the optic thalamus, but not including it.

Tentorium, "roof"—T. cerebelli, the fold of dura mater which roofs the cerebellum.

Telodendria—The terminal branchings of the dendrites.

Tigroid masses (Nissl substance)—Dentoplasmic bodies in the nerve cell which have especial affinity for certain stains.

Tuber—A swelling, as t. cinerum; a swelling in the floor of the fourth ventricle of a gray color.

Uncinate—Hook-shaped. U. fasciculus—See Table II.

Velum, "a veil"—A fold of the pia mater such as is found in the lateral ventricles and in the fourth ventricle.

Ventral—Pertaining to the anterior aspect of the body.

Ventricle—A cavity; one of the cavities of the central nervous system. The first ventricle is found within the right cerebral hemisphere; the second, within the left hemisphere; the third, between the hemispheres; the fourth, between the pons and medulla and the cerebellum; the fifth, between the folds of the septum pellucidum; the sixth, the canal of the spinal cord. All of the ventricles except the fifth are continuous.

Vaso-motor—A term applied to the nerves which control the size of the blood vessels.

Viscero-motor—A term applied to the nerves controlling the visceral muscles and glands.

Viscero-somatic—A term applied to reflex actions by sensory impulses from viscera affecting somatic-motor nerves.

Wallerian—See Degeneration.

Zona incerta—The upward extension of the reticular formation beneath the thalamus.

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